MODELING U.S. AIR FORCE OCCUPATIONAL HEALTH COSTS

THESIS

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Abstract

The primary purpose of this research was to improve the effectiveness of cost comparison analyses for the 75th Aerospace Medicine Group, Hill Air Force Base, Utah. Bioenvironmental engineers sought a more robust cost comparison tool, allowing engineers to quickly determine the viability of proposed occupational health-related expenditures. To justify the funding of potential projects, engineers must quantify the expected cost savings. Improved cost comparison analysis enables personnel to better justify worthy projects or filter out uneconomical solutions.

A secondary purpose of this research was to validate Department of Defense (DoD) occupational illness cost factors. This research effort focused on cost factors for illnesses resulting in no lost work time and for illness resulting in hospitalization. The existing cost factors were developed in 1988, and no continuity or existing methodology is available to determine how the factors were developed. We modeled direct medical expenditures related to occupational illness for a specific set of illnesses for active duty Air Force personnel to validate the "no lost time" factor. Additionally, we attempted to validate and apportion the hospitalization factor into direct and indirect occupational illness costs. This new knowledge will allow leaders to plan for and mitigate potential occupational illness costs.

Acknowledgments

I would like to express my sincere appreciation to my wife and son for their unwavering support throughout this endeavor. You stood by me every step of the way, believing in me more than I could ever believe in myself. I am forever grateful for your patience and encouragement.

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I. Introduction

Background

"Lack of evidence on cost-effectiveness is likely to be regarded as the same as activities demonstrated not to be cost-effective" (Miller, Rossiter, & Nuttall, 2002: 477). The preceding quotation states the overarching problem to improving occupational health processes. If cost estimating models cannot deliver reliable and defendable results, one should not expect investments to be made. This holds true in most instances, to include occupational health.

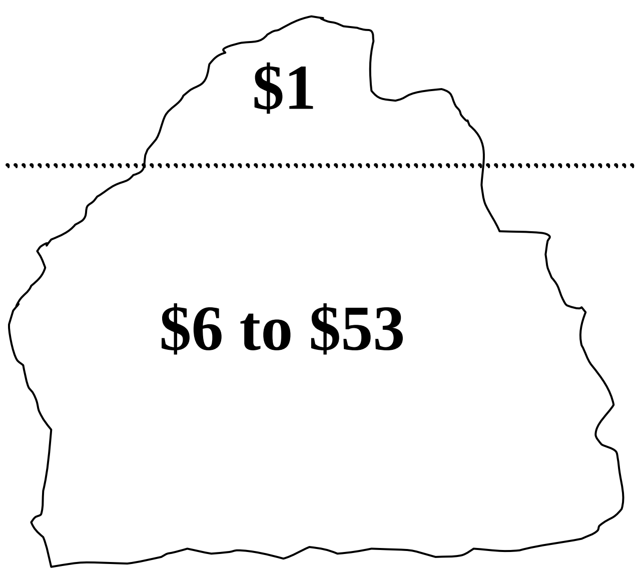
Convincing leaders to invest scarce resources on support functions is challenging, and rightly so. In a sense, commanders are fiduciaries to the taxpayers and must responsibly spend appropriated funds. While safety and occupational health requirements will likely rank high on any commander's priority list, such requirements seldom receive enough attention and justification to warrant funding.

Bioenvironmental engineers (BEEs) are tasked with ensuring occupational health requirements receive necessary attention. The 75th Aerospace Medicine Squadron, Bioenvironmental Engineering Flight at Hill Air Force Base, Utah (75 AMDS/SGPB) is a good example of a real-world operational unit that spends a considerable amount of time analyzing potential occupational health risks and initiatives for improvements. BEEs ensure workers are not exposed to dangerous workplace conditions. They advocate for process improvement or material substitutions that help mitigate potential hazards. While

BEEs often link tangible benefits such as cost or personnel savings to process changes, they also must consider the indirect costs associated with their recommendations.

The direct costs associated with the aforementioned initiatives are usually quantifiable. Direct costs of occupational illnesses include medical bills, insurance compensation, and other costs directly attributable to an occupational illness. Direct benefits also include savings of time, money, materials or any combination of the three. Capturing indirect costs is much more difficult. Occupational illness costs are synonymous to an iceberg floating in the water. See Figure 1 for an example, modeled after WSES.biz, 1992. The smaller direct costs, represented by the portion of the iceberg above the water, are visible and easier to tally. The disproportionately larger indirect costs, hidden below the water in the proverbial iceberg, have been estimated as high as $6 to $53 for each $1 of direct cost (Bird & Germain, 1996: 8). These indirect costs include employee turnover, lower morale, lost production, lost time wages, administrative burden, lost sales, and lost reputation/goodwill (Basu & Wright, 2005).

Figure 1. Total Cost of Illness "Iceberg"



<u>$1</u> Direct Costs for:
Medical Bills
Insured Costs

<u>$5 to $50</u> Ledger Costs for:
Building/Tool Damage
Equipment Damage
Legal Expenses
Emergency/Interim Supplies

<u>$1 to $3</u> Uninsured Costs for:
Investigations
Lost Productivity
Turnover
Lost Wages
Lost Goodwill

Illnesses are much more complicated to quantify than injuries. To differentiate, occupational injuries are readily attributable to a specific time, place and cause. Injuries are a result of "rapid, uncontrolled transfer of energy (chemical, electromagnetic, electrical, thermal, and mechanical) to an individual resulting in loss" (Slagley, 2008). Illnesses, on the other hand, are usually the result of repeated exposure to an adverse physical or chemical factor in the workplace.

The exact dollar figure for indirect illness costs is difficult to quantify for several reasons. As previously noted, occupational illnesses generally happen as a result of long-term exposure to a hazard. A patient may no longer be employed at the organization where the exposure occurred when he or she becomes ill. Doctors may not attribute the illness to an occupation, resulting in an under reporting of occupational illness and the associated cost. Occupational illnesses are difficult to link to specific causes. Illnesses could result from a multitude of factors, such as genetic disposition to disease, previous exposure, certain combinations of exposures, and general health of an individual. Finally, the severity and duration of illness are major factors in determining indirect costs. Illnesses lasting longer or causing more pain, suffering, and disability will be more expensive, simply based on the need for more medicine, longer hospitalizations, and higher percentages of worker's compensation.

Problem Statement

Bioenvironmental engineers seek a robust, transparent, and defendable tool to capture and articulate potential cost savings associated with occupational health expenditures, convincing decision makers that investing scarce resources in occupational health matters can be a highly effective use of funds. Engineers can accomplish this task by changing the way decision makers think in terms of cost-effectiveness. While initial capital costs may be much less for one alternative, the "cheaper" option with lower start-up costs may end up being the more expensive course of action in the long run. We will demonstrate how the entire life cycle costs must be considered before determining which alternative is best. The engineers are currently experiencing some difficulty accurately quantifying costs of potential occupational health projects.

The existing methodology compares the cost of a new process, such as new equipment, training, or manpower with the expected benefits, such as reduced materials/time/personnel. However, the existing methodology ignores the time value of money because engineers compare the initial cost of a new process with the cost of the current process. Some new processes may initially require a capital investment, making the project seem more expensive than it really is. The existing methodology does not allow engineers to accurately compare alternatives using concepts such as equivalent annual cost, breakeven analysis, or sensitivity analysis.

In addition to making the cost comparisons more accurate, bioenvironmental engineers must be able to determine the total cost of occupational illness. Total cost is determined by combining direct and indirect costs. Cost analysts need to apportion the DoD hospitalization cost factor into direct and indirect cost components. If analysts are able to apportion the costs, follow-on research and modeling efforts may allow engineers to use this information to further improve project justifications.

Research Objectives

Research Questions.

What is the most effective cost comparison methodology to use?

Is the DoD cost factor for occupational illness resulting in no lost time a reliable estimate for medical costs?

Can the DoD total cost factor for occupational illness resulting in hospitalization be separated into direct and indirect costs?

Hypothesis.

1. Using equivalent annual cost methodology when performing cost comparison analyses may result in choosing alternatives which were previously believed to be too expensive.

2. DoD cost factor for occupational illness resulting in no lost time is reliable.

3. DoD cost factor for occupational illness resulting in hospitalization is reliable.

Research Focus

The initial area of research focuses on determining the most effective cost comparison tool for situations typically encountered by bioenvironmental engineers from the 75th Aerospace Medicine Squadron at Hill Air Force Base, Utah. The end product will include a software-based user interface, such as a Microsoft Excel® spreadsheet, to facilitate analyses.

Additionally, research efforts will seek to validate existing DoD occupational illness cost factors. The DoD cost factor for no lost time estimates the direct medical expenses resulting from ambulatory visits for occupational illnesses. The cost factor for hospitalization supposedly estimates total cost, to include both direct and indirect occupational illness costs for hospitalization of occupational illnesses. According to DoD Instruction 6055.07, Accident Investigation, Reporting, and Record Keeping, the total costs include pay while away from work, medical treatment, hospitalization, dependent survival, training costs, burial, compensation, and disability retirement (DoD: 2008). We theorize the total costs are extremely elusive to capture, based on research of existing attempts at estimating indirect cost. We will use direct medical costs for Active Duty Air Force personnel from FY1999 to FY2008 for a specific set of 74 illnesses to model direct and indirect cost factors. We will then compare our new factors with DoD's attempt in 1988 to estimate illness costs.

Assumptions

Several assumptions must be made to facilitate the research efforts. To start, the author will develop a cost comparison methodology generic enough to cover foreseeable situations at an Air Logistics Center, such as Hill Air Force Base. The methodology will allow comparison of alternatives with equal project lives and allow users to vary inputs and see the resulting impact via a graphical display.

The methodology will also incorporate time value of money. Time value of money is normally associated with commercial endeavors when the interest rate, or cost of borrowing capital, and the discount rate, or expected return on capital, greatly affect the decision outcome. A dollar spent today has a different value than a dollar spent 10 years from now. While Air Force expenditures are not normally affected by interest rates from a "business" point of view, decision makers should consider discount rates and time value of money because some alternatives may require a significant outlay of capital in the short term. An appropriate discount rate will determine if the capital-intensive alternative is worth the risk.

When considering a discount rate in the final model, there are limitations of accuracy in estimating these rates. The Office of Management and Budget (OMB) recommends using a 7% internal rate of return (OMB Circular A-94). A single discount rate may simplify calculations for the end user instead of determining a variable rate based on the length of project. We do not feel setting the discount rate at 7% compromises the final model. If a sensitivity analysis of several alternatives results in changing in a decision based on the discount rate fluctuation, we feel other tangible factors will take precedence in the decision process.

Implications

The cost comparison tool could have potential service-wide implications. Many decisions makers throughout the Air Force, whether they are bioenvironmental engineers, civil engineers, logisticians, or front-line managers, may not have the time or tools necessary to accurately compare alternatives when allocating budgets. The end product of this research effort will allow decision makers to have more accurate information. With more accurate information, we anticipate better decisions, ultimately resulting in more effective use of taxpayer dollars.

A new understanding of how to reduce medical costs may increase occupational health expenditures. As a result, occupational health expenditures may lead to safer working environments through reduced occurrences of occupational illness. According to the Air Force Operational Risk Management (ORM) website, “ORM is a decision-making process to systematically evaluate possible courses of action, identify risks and benefits, and determine the best course of action for any given situation” (ORM University, 2008). Decision makers could lower overall costs and improve ORM, creating a win-win situation for everyone.

Preview

Discussion will begin with existing literature on the topic of occupational illness, as well as attempts to capture costs through various methods. The author will develop a cost comparison tool to meet the customers' needs, allowing comparison of multiple options across a range of user input criteria. The author will then develop a regression model to validate DoD cost factors, based on the amount of direct medical costs. Finally, the author will discuss the applicability for service-wide use, as well as submit recommendations to improve analyzing occupational illness costs in the future.

II. Literature Review

Most pertinent literature regarding occupational illness modeling stems from ground-breaking efforts by Dr. Paul Leigh. His team performed the most complete effort to date of estimating direct and indirect costs. Additionally, Dr. Katharyn Grant published a cost/benefit analysis handbook targeted to Environmental, Safety and Occupational Health (ESOH) personnel. Dr. Leigh's and Dr. Grant's efforts form the backbone of our research efforts. Follow-on efforts by other researchers provide refinement and deeper discussion of the challenges of modeling occupational illness costs.

Historical Perspective

Occupational illness prevention has long been recognized as a critical component of creating a safe and healthy workplace. In the late 1960s, President Richard Nixon pointed out the need for increased emphasis on workplace health (Burk & Moeller, 1975: 2). In a message to Congress, President Nixon compared the adequacy of federal safety and health programs to private businesses. Apparently, federal program administrators were not keeping up with the advances in technology and manufacturing. As a result of proposed standards, Congress created the Occupational Safety and Health Act of 1970 (Ibid: 3). However, the act specifically excluded federal agencies by defining an employer as "…a person engaged in a business affecting commerce…" (Ibid). Upon further refinement of OSHA directives, Air Force leaders created Air Force Occupational Safety and Health (AFOSH) equivalent regulations. In fact, the verbiage of the Air Force regulations called for safety and health standards equal to or better than OSHA standards. AFOSH programs have since evolved under several organizations, such as Air Force

ESOH, Air Force Institute of Occupational Health (AFIOH), and finally the U.S. Air Force School of Aerospace Medicine, located at Brooks City-Base, Texas.

The Air Force definition of occupational illness is “any abnormal condition or disorder, other than an occupational injury, caused by exposure to environmental factors related to employment” (Grayson, 1990: 2). The Occupational Safety & Health Administration (OSHA) defines occupational illness as a physiological harm or loss of capacity produced by systematic infection; continued or repeated stress or strain; exposure to toxins, poisons, fumes, etc.; or other continued and repeated exposures to conditions of the work environment over a period of time. For practical purposes, an occupational illness or disease is any reported condition not meeting the definition of traumatic injury (www.osha.gov). To properly differentiate between injuries and illnesses, consider that injuries are a result of an instantaneous event whereas illnesses are usually a result from repeated exposure over time.

Cost/Benefit Analysis Methods

In 2001, Dr. Katharyn Grant created a technical guide to assist ESOH workers with creating economic or cost-benefit analyses. Engineers could then use the analyses to enhance recommendations for ESOH solutions at Air Force installations (Grant, 2002: 1). Dr. Grant noted that cost has always been a significant factor when evaluating workplace changes. She highlighted the importance for ESOH professionals to fully understand costs associated with their recommendations. Decision makers usually understand benefits expressed in financial terms. Dr. Grant’s report provides the tools necessary to express costs and benefits in a manner in which decision makers should readily understand (Ibid).

Cost/benefit analyses generally follow a common path of evaluation steps (Ibid). The basic plan of action for most economic analyses is:

- Define project goal or desired outcome
- Identify potential alternatives
- State assumptions
- Determine costs
- Detemine benefits
- Compare costs/benefits for alternatives
- Perform sensitivity analysis
- Select alternative with most advantageous mix of costs/benefits

Properly comparing costs and benefits is perhaps the most challenging technical aspect of performing an economic analysis. Three methods were compared: net present value, payback method, and return on investment. Those methods will be discussed and compared in the following paragraphs.

Net present value (NPV) provides one value of all costs and benefits across the life of a project. Future costs and benefits are discounted back at an appropriate rate to provide an accurate comparison of expenditures or benefits occurring at different times. See Chapter 3, Methodology, for further explanation of discounting. The NPV formula is:

$$NPV = FV\ (1 / 1 + r)^t - IC \qquad (1)$$

where NPV is net present value, FV is future value of benefits, r is the discount rate, t is the number of time periods the cost or benefit occurs, and IC is the initial capital expense of the project (Ibid: 10). ESOH professionals may compare the NPV for a number of options.

Any NPV above zero means the benefits outweigh the costs. For example, consider making a choice between Option A and Option B. Option A requires an initial capital expense of $100 but returns a $200 benefit in 3 years. Option B also costs $100 upfront but returns a $50 benefit in 3 years. Using Equation 1 with a 7% value for r, we see that Option A provides a NPV of $63.26. Option B provides a NPV of -$59.19. Option A is better than Option B because Option A has a positive value. Option B costs more money than it provides over the life of the project. From a strictly financial viewpoint, the alternative with the highest NPV will normally be the best choice.

Instead of comparing the NPV of alternatives, decision makers may want to know how quickly their "investment" will pay for itself through reduced costs. Such an analysis is known as the payback method. The payback method formula is:

$$PB = C / S \tag{2}$$

where PB is the payback period (months, years, et cetera), C is the initial cost, and S is the recurring benefit or savings. If the payback period is negative, the alternative costs more than it saves (Ibid: 12). This method of economic analysis is flawed for several reasons. First, the method does not consider any cost or benefits beyond the payback. Second, while some methods of payback incorporate discounting or time value of money, Dr. Grant's simplified version shown in Equation 2 does not. Finally, the benefits must be fairly consistent for this equation to work properly. For example, if the initial cost was $100 and the recurring savings per period was $50, we calculate a payback period of 2 periods. However, based on these inherent flaws of this methodology, the payback method will not be considered as a viable option.

Finally, leaders may want to know the return on their investment. Return on investment (ROI) "represents the percentage of the costs associated with implementing a project that are recovered as savings over a set period of time" (Ibid). The formula for ROI is:

$$ROI = (S / C) * 100\% \tag{3}$$

where ROI is return on investment, S is the annual benefit or savings, and C is the initial cost. The ROI method is useful in showing what percentage of the initial cost is recovered for each time period. This method may be useful as a secondary consideration. However, ROI does not convey the magnitude of cost or benefits. For example, a project with annual savings of $5,000 and initial cost $100,000 will have the same 5% ROI as a project with annual savings of $100 and initial cost of $2,000. Commanders are often constrained by a one-year budget cycle for specific appropriations. The dollar value of costs and benefits is often a huge limiting factor, and ROI does not convey this information directly.

Occupational Illness Modeling

Perhaps the most relevant literature regarding parametric estimation of indirect costs appears in *Occupational Injury and Illness in the United States: Estimates of Costs, Morbidity, and Mortality*. Dr. J. Paul Leigh, et al, provided an early attempt at quantification of direct and indirect injury and illness costs in the United States. Indirect illnesses include lost earnings, lost home production, and lost fringe benefits (Leigh, Markowitz, Fahs, Shin, & Landrigan, 1997: 1557). The authors tied the occurrence of certain illnesses in the United States to the probability of the illness occurring due to occupational conditions.

The authors provided confidence intervals of illness occurrence along with point estimates. It is important to distinguish between the two now. Point estimates are convenient, allowing the end user to have a specific number for further estimates and calculations. However, the confidence interval approach provides a more realistic, accurate range of possible values. This is especially true when using the ranges to provide potential future costs. For example, it cannot be said with much fidelity that 8% of all cardiovascular disease cases in the next five years are work-related. However, based on documented research, researchers can estimate that 6% to 10% of cardiovascular disease cases may be work-related (Leigh J. P., Markowitz, Fahs, & Landrigan, 2000: 60). Uncertainty may hamper the acceptance of cost models. It is critical for the cost analyst to communicate the meaning and importance of confidence intervals when delivering cost estimates to the decision makers. Even so, Dr. Leigh also used point estimates calculations in order to streamline estimation processes. Dr. Leigh assumes a normal distribution for the attributable factors, and we will assume likewise.

Some illnesses are mostly attributable to a particular job, such as mesothelioma and pneumoconiosis (Ibid: 66). Other illnesses occur “naturally” and through exposure to catalysts in and out of the workplace, such as many forms of cancer (Leigh J. P., Markowitz, Fahs, Shin, & Landrigan, 1997: 1559). The authors applied an attributable risk proportion model for illnesses not 100% attributable to work. The model was created using results from numerous existing medical studies relating specific diseases to what proportion resulted from work-related exposures. Other studies acknowledge the increased risk of cancer in some occupations without clearly identifying the specific causes. For example, farmers may have higher rates of lymphoma and fire fighters may have higher rates of brain cancer (Ibid). Also, smoking warrants special consideration. Smoking is a personal choice and should not be included as a workplace toxin exposure. Conversely, the effects of second-hand smoke should be included for certain occupations where workers are constantly exposed, such as bars and some restaurants.

The cost model developed by Dr. Leigh, et al, uses present value as shown below:

$$PV_{Death} = \Sigma\, P_{y,s,n} * (M_{s,n} + H_{s,n} + F_{s,n}) * LFPR_{s,n} * (1+g)^{n-y}/(1+r)^{n-y} \quad (4)$$

*Note: Summation is from y = n to 75, representing a range of possible working years.

Above, PV_{Death} is the present discounted value of loss from illness; $P_{y,s,n}$ is the probability a person of age n, sex s will survive to age y; $M_{s,n}$ is the mean annual earnings of a person of sex s and age n; $H_{s,n}$ is the value of household production of a person of sex s and age n; $F_{s,n}$ is the fringe benefits, again based on sex s and age n; LFPR is the labor force participation rate (0.0 to 1.0); g is the increase in labor productivity, assumed by the researchers to be 1%; and r is the real discount rate, assumed to be 4% (Ibid: 1561). Mean annual earnings includes direct salary. Household production includes the value of household services such as lawn care, general repair, cooking, cleaning, et cetera. Examples of fringe benefits include loss of vacation time and loss of employer/employee contribution to retirement accounts. The household production and fringe benefits, as well as the mean salary based on demographic data, may oversimplify the true value of loss from illness or injuries. However, to date, it represents the best attempt at capturing these elusive costs and modeling the estimates for further research.

Based on the number of reported illnesses and the estimated portion of those illnesses occuring due to occupational exposure, the authors determined there were approximately 817,000 to 907,000 new occupational illnesses in the United States in 1992. As shown in Table 1, the task of estimating the number of occupational illnesses is very challenging. The numbers of occupational illnesses are not readily tracked by a central database. Different databases track different sectors of the workforce, and the possibility to miss counting illnesses or double-counting illnesses is ever present. Table 1 provides an excellent snapshot of how daunting a task it is to calculate the number of illnesses occuring in this country based on occupational exposure.

Table 1 also provides good rationale to implement the recommendations included in Chapter 5. Concise, purposeful, accurate databases would negate the ambiguous ranges of illness and injury occurring in the United States. Without a firm number of cases to start with, one cannot hope to accurately estimate total costs. We are immediately faced with much uncertainty, which will only increase as attributable factor ranges are added to the estimation.

Table 1. Number of Illnesses, US (1992)
(Reproduced with permission from J.P. Leigh et al, 1997)

Illness/Source of Data	Estimated Attributable Number of New Cases in US	Percentage Attributable to Occupation	Estimated Number of Occupational Illnesses
Cancer	1,113,100	6% - 10%	66,790 - 111,130
Coronary heart disease	730,000	5% - 10%	36,500 - 73,000
Cerebrovascular disease	101,00 - 144,000	5% - 10%	5,050 - 14,400
Chronic obstructive pulmonary disease	1,500,000	10%	150,000
Subtotal			258,340 - 348,710
Bureau of Labor Statistics Annual Survey			457,400
National Institute of Occupational Safety and Health			14,250
Public Sector Employees			92,010
Total*			**817,015 - 907,385**

* Approximately 5,000 cases removed to avoid estimation overlap

The authors used a median value of 858,165 occupational illnesses for further calculations. Using Equation 4, the direct cost of occupational illness for this time period was 16.07 billion dollars and the indirect cost was 9.47 billion dollars, as shown in Table 2. To summarize, the authors calculated each dollar of direct costs results in 59 cents of indirect costs (Ibid: 1562). If only $1 out of $1.59 is being captured, this equates to approximately 37% of the total cost of occupational illness not being captured. This is in stark contrast to previous estimates of $6 to $53 of indirect costs for each $1 of direct costs. The extreme difference may be due to other indirect cost factors not captured in the Leigh et al model. Or, it may mean earlier estimates were greatly overstated.

Table 2. Number and Costs of Illnesses, US (1992)
(Reproduced with permission from J.P. Leigh et al, 1997)

	Number	Direct Cost	Indirect Cost	Total
Deaths	**60,293**	**$10.70B**	**$9.00B**	**$19.70B**
Morbidity	**858,165**	**$5.37B**	**$0.47B**	**$5.84B**
Totals		**$16.07B**	**$9.47B**	**$25.54B**

In Dr. Leigh's sensitivity analysis, he notes that he did not adjust discount rates or growth rates in the present value model. His team found various discount rates did not greatly alter the findings. Significant cost variation depended on the numbers and types of illnesses instead of discount/growth rate changes.

The indirect costs may be underestimated due to the exclusion of pain and suffering. Additionally, the medical cost data excluded California and New York due to the disproportionately high cost of healthcare in these two states. Finally, the estimates ignored the value of home care provided by the family, effects of disabled or absent parents, and wage losses attributed to disabled persons employed in relatively less lucrative jobs (Ibid: 1565).

The article provides an excellent framework for this research effort. The authors provide ample explanation as to why cost estimates for indirect costs had such a large range. Unless illnesses are attributable to workplace exposure, the cost of occupational illness cannot be accurately estimated. To further complicate matters, most illnesses do not surface until many years after exposure, making it more difficult to tie back to a particular workplace.

Economic Value of Occupational Health Services

Miller, Rossiter, and Nuttall attempted to determine an economic value of occupational health services in a workplace (Miller, Rossiter, & Nuttall, 2002: 477). While the study was based in the United Kingdom, the external validity of the study allows analysts to make several direct comparisons. To start, the cost of sick workers is easy to determine. The authors show the total cost of sickness absence led to 12 billion British Pounds, simply based on the average lost working days per year and the average cost per worker per day. While such generalizations may not be very accurate in the aggregate, one cannot overlook the impact occupational health services may have in reducing these costs (Ibid: 478).

There is a major problem with measuring the impact of occupational health investments. The impact is the absence of an occupational illness or injury. Counting the number of times something does not happen is a challenge. Developing a causal relationship between an illness not occurring and the expenditures made on occupational health may be impossible. Measuring a reduction in illnesses may be more appropriate. But, other causes may exist. For instance, a new commander can redirect the corporate culture, focusing more on process improvement, safety, and proficiency. Any one of these factors, in addition to increased morale, could lead to a reduction in illness. Controlling for every alternate explanation is nearly impossible, especially when organizational leaders want assurance they are spending money on effective programs.

The first model compared the direct cost of administering an occupational health service within an organization to the expected benefits. If the benefits exceeded the costs, the program was justifiable. Such benefits included increased health and morale, increased performance and productivity, reduced medical/legal costs, enhanced workplace safety, and reduced sickness absence (Ibid: 479). A few drawbacks immediately come to mind. It seems only three of the five broad categories are quantifiable. While absences, productivity or medical costs can be measured, health, morale, and workplace safety are not as easy to quantify. Even so, this simple break-even analysis has merit and may be an appropriate area of future research.

Next, the authors attempted to give a valuation to occupational health services by surveying 38 key decision makers. The decision makers were asked to give a hypothetical monetary estimation, comparable to an insurance premium making an occupational health service desirable. The authors calculated the difference between the hypothetical estimate and the actual premium to determine the "net value added" (Ibid: 480). This method evaluates a manager's perception of the value of a service, introducing a fair amount of subjectivity into the process.

Finally, the authors employ an empirical approach with primary data collection. Three categories of outcomes of occupational health services were developed. The first category is unobservable outcomes, such as reducing risk and increasing safety awareness. The second category is clearly observable outcomes, such as sick days, health costs, and frequency of illnesses. The third category is outcomes which must be "estimated by proxy, using other observable data" (Ibid: 481). The quality of life of employees is a major element in the authors' empirical approach to modeling costs. However, the authors do not move beyond the concept of empirical modeling. They limit discussion to developing some type of cost per quality-adjusted work day factor without showing an actual model or empirical results.

Managers may not fully understand the costs or benefits of occupational health services. From a purely business standpoint, key decision makers may only need to know the benefits outweigh the costs. If this is the case, analysts would only need to quantify occupational health benefits to the break-even point. One must consider the costs of long-term solutions, as well. There is much uncertainty involved when quantifying benefits to an employee after he or she has been retired for 10 years. This approach may lead to minimizing costs or overstating benefits to reach favorable conclusions. Clearly, a more empirical approach is desired.

Social/Economic Impacts of Workplace Illnesses

Occupational illnesses have many impacts. Workers, employers, families, and society as a whole are all impacted. There are monetary costs and social costs. It is troubling that only a fraction of the total "bill" is understood. Some estimates suggest for every week a worker is off the job due to an occupational illness or injury, he or she loses an average of ten thousand dollars in earnings (Boden, Biddle, & Spieler, 2001: 399). Employees lose direct wages when they become sick or injured. Additionally, they may lose their place in seniority or promotions and may have to accept other jobs with lower pay to accommodate any limitations imposed by the illness or injury. This figure, of course, depends on the type, severity, and duration of illness, as well as the employee's socio-economic status before, during, and after the illness. The authors point to research showing ill workers are unable to fulfill social, work, or family roles. The resulting "diminished earnings, long-term physical limitations, depression, fear, and anger" further increase their psychological and economic suffering (Ibid).

In the past, the only costs most employers considered stemmed from worker's compensation. However, worker's compensation is just one of many other factors. As noted earlier, indirect costs include such things as training and hiring replacement workers, lost productivity, downtime, redundancy as a risk management strategy, and decreased morale/public relations. To make matters even more complicated, the aforementioned costs will vary greatly depending on the occupation, frequency/severity/duration of illness, and a host of other demographics. The expansive list of variables presents a considerable challenge to developing an all-encompassing indirect occupational illness cost model. The poor quality and quantity of available data does not help the issue (Ibid: 401).

Estimating Indirect Costs of Illness: Assessing Forgone Earnings

One of the biggest indirect costs of occupational illness is the loss of earnings experienced by an employee. Calculating these forgone earnings would capture a significant portion of the indirect cost "iceberg." However, there are serious issues with relying solely on forgone earnings calculations. As Dr. Glied points out, "while the forgone earnings approach is certainly less complicated than measuring willingness to pay for increased risk, it will not provide appropriate or consistent estimates unless it is used with great care" (Glied, 1996: 1728).

The forgone earnings approach methodology allows the analyst to approximate the wages an employee would have likely earned had he or she not become ill or injured. The average earnings of a cross-sectional pool of people sharing similar demographics are discounted back to an established base year. The forgone earnings equation is as follows:

$$\text{Forgone earnings} = \sum E_{n+i,\, m} \tag{5}$$

where E is the estimated earnings for a person age n in year m. The summation is from 1 to i, based on the necessary span of time. The author uses a generic time period of 15 years in the study. However, a 20-year old individual will likely require longer analysis while a 60-year old individual may require less. In the study, the author shows a 20-year old Caucasian male would likely earn $161,157 in the 15 years spanning from 1973 to 1988. The dollar figure is set to a base year of 1980, discounted at 4% per anum. The actual earnings for this group and time period were $128,723. This particular example shows a resulting error of 20.1%, one of the worst error rates when comparing the author's estimations to actual earnings for particular groups and times (Ibid: 1725-1726).

There are some marked problems associated relying solely on the forgone earnings approach. First, this approach is only useful if calculating earnings forgone due to death. Otherwise, it would be difficult to determine the length of time an individual will remain out of work due to the injury or illness. Even so, using the average life expectancy based on the age of the individual at the time of death introduces its own source of error. Also, there is an enormous amount of variation in the estimates, as shown in the above paragraph. Business cycles, advances in technology, labor market conditions, and population changes all impact earnings estimates. Finally, the younger the employee is at the time of death/injury/illness, the more divergence present in the real earnings growth. Sensitivity analyses may help control for some of these sources of error. The extreme variance of forgone earnings estimates and substantial impact of external factors (business cycles, labor markets, et cetera) will not provide decision makers the clean, accurate, and convenient indirect cost estimate they may desire.

Magnitude of Mortality

Dr. J.P. Leigh et al developed the first relatively transparent occupational illness cost model by estimating the portion of illnesses attributable to occupational exposure. Dr. Kyle Steenland et al used similar attributable factors to specifically determine the magnitude of deaths from a specific set of diseases. By analyzing causes of death in the U.S. in 1997, Steenland et al gathered International Statistical Classification of Diseases and Related Health Problems codes, 9th Edition (ICD-9). The ICD-9 codes are used by medical professionals to describe illnesses and injuries, making computer data entry and analysis more efficient. Each ICD-9 code is directly related to a particular illness or injury. The authors calculated attributable factors for a specific set of illnesses and multiplied the factors by the total number of the illnesses reported in 1997. The following is a list of illnesses reviewed in the document: pneumoconiosis, occupational asthma, chronic obstructive pulmonary disease (COPD), tuberculosis, and specific cancers. The attributable factor equation is as follows:

$$\text{Attributable Factor} = \frac{P\,(E)\,(RR - 1)}{1 + P\,(E)\,(RR - 1)} \tag{6}$$

Where P (E) is the proportion of the general population exposed to a particular agent, and RR is the relative risk of death or disease for someone exposed as compared to someone not exposed (Steenland, Burnett, Lalich, Ward, & Hurrell, 2003: 463).

While the attributable factors were used for most diseases, some diseases warranted special attention. For instance, it can be argued pneumoconiosis is 100% attributable to occupational exposure (Ibid: 464). The attributable factor for COPD was taken from “community-based studies of the general population rather than from workplace- and industry-specific studies" (Ibid: 465). Other case-specific adaptations were made in the study, such as eliminating causes of death with less than 50 deaths in the year. Also, occupational noise, shift work, and second-hand tobacco smoke were not considered as a cause of death themselves, but as compounding factors to other causes of death such as coronary heart disease. Table 3 shows Steenland's results for job-related deaths caused by illness in 1997. This table once again points out the complexity of quantifying victims of occupational illness. The wide range of deaths reported by Steenland in Table 3 and the range reported by Leigh in Table 1 lend some credibility to the wide variance in indirect costs initially reported by Basu and Wright in Figure 1.

Table 3. Estimated Number of Job-Related Deaths Due to Illness, US (1997)

(Reproduced with permission from Dr. Kyle Steenland et al, 2003)

Cause	Number of Occupational Deaths
Selected Respiratory Diseases	6,805 - 26,686
Selected Cancers	12,086 - 26,244
Coronary Heart Disease	6,037 - 18,253
Selected Renal Diseases	328 - 580
Other Occupational Diseases	50 - 350
Total	**25,910 - 72,121**

The authors acknowledge the results were "broadly consistent" with other estimation efforts such as Dr. Leigh's (Ibid: 474). However, several sources of potential underestimation and overestimation were noted. The results could be underestimated due to the limited set of diseases captured in the study. Many diseases are believed to be caused by occupational factors but were excluded unless scientific research established a direct relationship. Also, diseases were excluded if less than 50 deaths were reported. Overestimation could take place when developing confounding attributable factors, such as how or if smoking increases the risk for coronary heart disease. Also, estimating a composite attributable factor for several diseases or risk factors could lead to overestimation. The mortality estimation results place occupational disease-related deaths as the 8^{th} leading cause of death in 1997, after diabetes but before suicide. To add some perspective, deaths from occupational-related diseases are estimated to be greater than yearly motor vehicle deaths (Ibid: 477).

As the aforementioned research efforts clearly demonstrate, modeling occupational illness costs is difficult. There is uncertainty in the exact number of illnesses as well as the percent caused by occupational exposure. After considering the DoD's approach to estimating illness costs, we will build upon the tools and techniques developed in previous research efforts by developing a methodology to model occupational illness costs for Air Force personnel.

Accident Investigation, Reporting, and Record Keeping

The Department of Defense, in compliance with OSHA guidelines, has established its own accident/illness investigation, reporting and record keeping. DoD Instruction 6055.07, updated in April 2008, outlines the processes for the aforementioned activities. These processes are specifically developed to comply with federal job safety mandates, such as Executive Order 12196 and 29 Code of Federal Regulations (CFR) 1960 (Defense, 2008: 2).

DoD policy authorizes the implementation of workplace programs for two purposes:

1. “Investigate, report, and keep related records on accidental death, injury, occupational illness, and property damage for DoD accidents covered by this Instruction and/or specific statutory authority (Ibid).”

2. “Prescribe and enforce regulations directly related to investigation, reporting, and keeping records on accidental death, injury, occupational illness, and property damage (Ibid.)”

Such programs may help leaders utilize historical data as appropriate when developing or acquiring new acquisition systems. The data may also be used to estimate future costs based on past experience.

To aid in estimating future costs, DoD personnel developed cost estimation factors in 1988. The factors estimate costs when personnel succumb to illness or injury on the job. We attempted to ascertain the methodology behind the DoD cost factors. Unfortunately, the methodology is not available, either due to lack of continuity or unfamiliarity with illness estimating techniques. As stated in the document, “They [cost factors] were developed in 1988 and have not been updated so that analysts can make generalized comparisons against historical data (Defense, 2008: 35).”

Fortunately, we are able to properly analyze historical Air Force medical cost data for the past 10 years in order to update or validate the outdated cost factors for the DoD. To summarize Table E7.T1, Cost Standards, enlisted and commissioned personnel cost \$120 per day for illness resulting in no lost time. We assume no lost time simply means an employee falls ill at work, seeks care at a treatment facility, then returns to work on the same day or at latest the following day. For illnesses resulting in hospitalization, enlisted and commissioned personnel cost \$466 per day. We assume days of hospitalization equate to bed days as reported by medical cost databases. Again, these figures are based in 1988 dollars.

The DoD Instruction adequately outlines responsibilities, processes, and other administrative issues. However, there is no mention or reference as to how the cost factors were developed. We seek to validate these factors or recommend updated factors for more accurate illness cost estimating for the DoD.

Now that we have examined existing relevant research, we can develop a methodology that will allow us to answer our research questions. First, we will develop a suitable cost/benefit analysis tool. Then, we will develop a methodology to analyze the DoD cost factors.

III. Methodology

Cost Comparison Analysis

Net Present Value.

To begin discussion of cost/benefit analysis methods, some basic assumptions must be established. Many economic analysis methods incorporate a discount rate in the calculations. Discount rates determine the required return rate of investing capital. The basic premise of including a discount rate is to account for the time value of money. Simply put, it is cheaper to spend money later versus now. It is better to earn money now versus later. We will use discount rates to quantify the potential costs and benefits of investing government appropriations.

Government appropriations are much different than corporate funding because they are not impacted as much in terms of traditional interest rates for borrowing or lending. When a commander needs capital to build a new road, she either uses available funds or asks higher headquarters for more budget authority. To simplify discussion, there are no bonds to issue, stocks to sell, or loans to take. Operations and Maintenance (O&M) funds are generally available for only one year. However, interest rates can enter the picture when the time frame exceeds one year.

According to Air Force Manual 65-506, Economic Analysis, analysts should use an interest rate equal to a 3, 5, 7, 10 or 30 year Treasury bill/bond when evaluating the net present value of a potential project. It is important to distinguish between interest and discount rates. Interest rates are the cost of borrowing money and discount rates are the expected return on the capital investment. The two concepts are similar and are even used interchangeably in some texts. The timeline of the project will dictate the applicable

Treasury rate to use (SAF/FMC, 2004: 10). The Treasury rates are essentially the government's cost of borrowing money. As such, the rates serve as a proxy for discounting government appropriations to determine a net present value.

In contrast, the OMB states a 7% rate shall be used (whitehouse.gov). We feel this set 7% rate is simple, effective, and robust enough for the types of cost/benefit analyses to be conducted by bioenvironmental engineers. The OMB rate removes one more variable from the equation, simplifying the process even more. Further, Dr. Leigh's previously mentioned research showed the interest rate or discount rate was not a significant factor in the sensitivity analysis.

Net present value is a method of determining a value of an alternative at a given point in time. All costs and benefits are expressed in terms of a common time. Future costs and benefits are discounted back at an appropriate interest rate. As noted earlier, the Air Force Manual 65-506 contains methodology for discounting by using Treasury Bill rates. To demonstrate net present value, consider the following example.

The above timeline represents an initial cost of $100 at Time 0, noted by the downward pointing arrow, and a future expected benefit of $200 at Time 1, noted by the upward pointing arrow. Assume a nominal interest rate of 7%, as recommended by the OMB. Whether or not spending $100 now to receive $200 in the future depends on two factors. The first factor is time, specifically the length of time between an expenditure and the receipt of any future benefit. The second factor is the interest rate. Recall from Equation 1 the formula for net present value: NPV = FV $(1 / 1 + r)^t$ - IC. The present value of the $200, discounted back one period at 7% equals $186.92. The net present value is simply the present value of future benefits minus the present value of current and future costs. In this example, simply subtract $100 from $186.92 to get a net present value of $86.92. This value represents the value of benefits above and beyond any costs incurred. As long as the net present value is greater than zero, it makes financial sense to make the investment.

Equivalent Annual Cost.

Net present value is a powerful tool for determining when to make an investment. However, it may not be the best analysis method when evaluating government, or public-sector, projects. Public-sector economic problems are often more difficult than private-sector economic problems for several reasons including (Eschenbach, 2003: 363):

- Benefits are difficult to determine/quantify in terms of money
- Long time horizons increase risk
- Policy/bureaucracy challenges
- Interest rate selection is difficult

To further complicate matters, the short annual cycle of O&M funding hampers decision makers from fully considering future costs and benefits of a project. Most decision makers tend to focus on the annual impact to the overall budget. The Equivalent Annual Cost (EAC) is the solution to this problem.

The EAC is a uniform dollar amount at the end of each period, equal to the overall costs for a project (Ibid: 139). The EAC will allow comparison of equivalent annual costs between two alternatives, giving commanders an "apples to apples" comparison of the long-term impact on a budget. Using some simple equations, the EAC can be calculated based on a known present value or cost. The formula for computing an EAC based on a present value is:

$$\text{EAC} = (\text{PV}*((i*(1+i)^N)/((1+i)^N - 1))) + \text{RC} \qquad (7)$$

where PV is the present value of the initial cost, i is the discount rate, N is the number of periods, and RC is the recurring cost.

While the formula may initially appear daunting, there are several ways to automate the process such as using a financial calculator, spreadsheet tool, or using end-of-period compound interest factors available in many economic text books. We will use a spreadsheet tool to simplify comparisons. The formulas above can be programmed into a write-protected worksheet, allowing engineers to make quick calculations and evaluate alternatives. The following is a screenshot of a possible spreadsheet-based analysis tool:

Figure 2. Excel®-Based Equivalent Annual Cost Tool

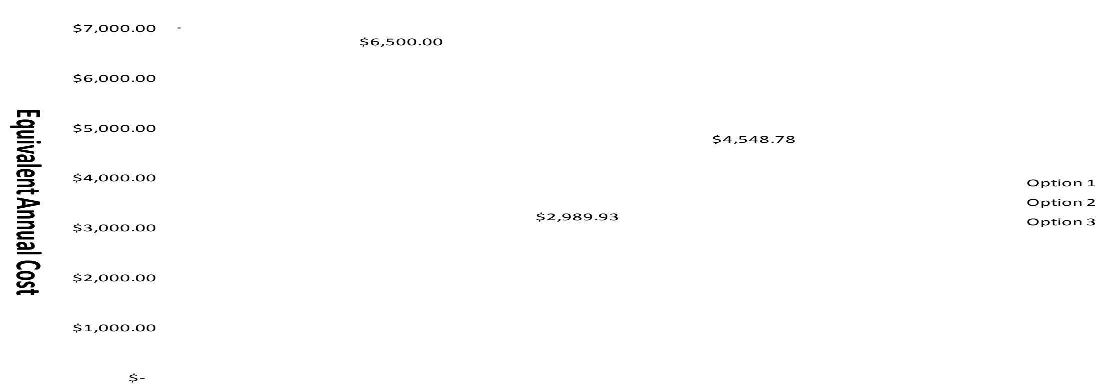
**Only change cells highlighted in yellow
**Lowest EAC is best option financially

Life Span (years)	10
Interest Rate	7.0%

Option 1	
Initial Cost	$ -
Recurring Cost	$ 6,500.00
EAC	$ 6,500.00

Option 2	
Initial Cost	$ 21,000.00
Recurring Cost	$ -
EAC	$ 2,989.93

Option 3	
Initial Cost	$ 10,000.00
Recurring Cost	$ 3,125.00
EAC	$ 4,548.78



In Figure 2, three options are compared with differing initial and recurring costs, but similar life spans and discount rates. Option 1 has no initial cost, but a high recurring cost each year. The EAC for Option 1 is equal to the recurring cost. Option 2 has the highest initial cost, but no recurring cost. The EAC for Option 2 is the initial cost spread across the life span of the project (10 years), discounted by the interest rate of 7%. Finally, Option 3 has a lower initial cost compared with Option 2 and a lower recurring cost compared with Option 1. The EAC for Option 3 is the initial cost spread across the life span of the project (10 years) plus the recurring cost per year. As shown in the bar graph, Option 2 is the cheapest in terms of equivalent annual cost, followed by Option 3 and then Option 1. This is a good example of how decision makers may be misled by high initial costs in favor of an affordable recurring cost. Even though Option 2 would require a substantial investment up front, it is the cheapest option in terms of equivalent annual cost.

Breakeven Analysis.

In addition to EAC, commanders may also want to know at what point options become more expensive than one another. A breakeven analysis will show the best option for a given range of time. Again, spreadsheet applications can easily be programmed to display a line graph. The lowest line for any given time is the cheapest option. The options have equal EACs at the intersection points. This method also allows some sensitivity analysis by allowing the decision maker to determine at which time period the options are equal. If there is uncertainty in the lifespan of the project or equipment to be purchased, the breakeven analysis can help show at what range the project or expenditure is still viable. Figure 3 shows an example of a spreadsheet tool for breakeven analyses:

Figure 3. Excel®-Based Breakeven Analysis Tool

**Only change cells highlighted in yellow

**On the graph, the lowest option is financially the best option for a given range of periods

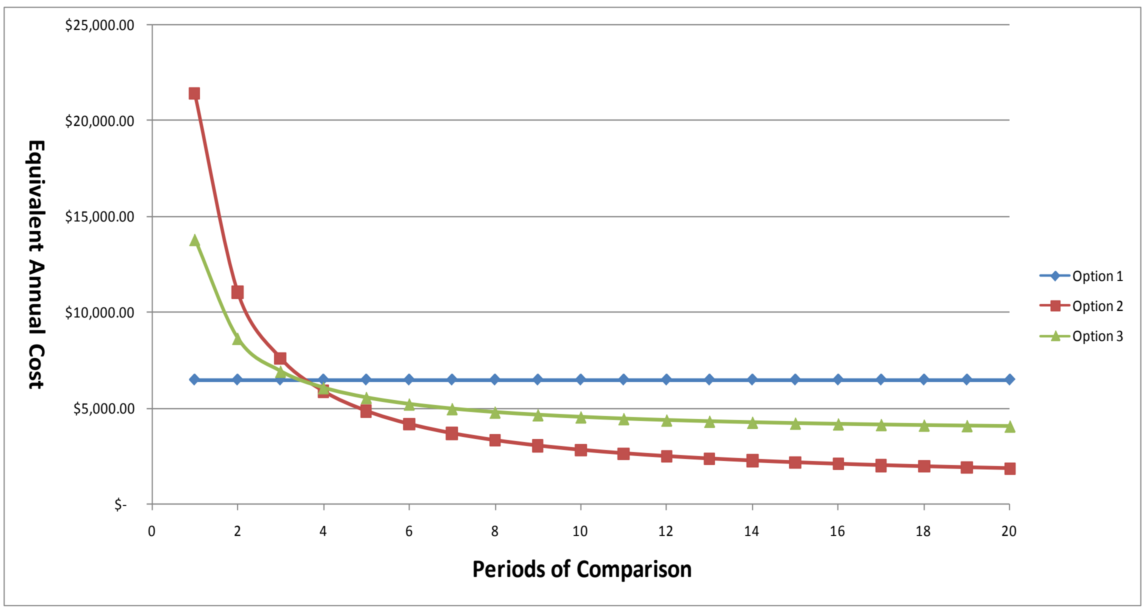
Discount Rate	7%

Option 1	
Initial Cost	$ -
Recurring Cost	$ 6,500.00

Option 2	
Initial Cost	$ 20,000.00
Recurring Cost	$ -

Option 3	
Initial Cost	$ 10,000.00
Recurring Cost	$ 3,125.00

Option 1 versus Option 2 Breakeven Analysis	Option 2 versus Option 3 Breakeven Analysis	Option 1 versus Option 3 Breakeven Analysis
3.6 Periods	3.7 Periods	3.4 Periods



The same initial and recurring cost information from the EAC example were used. The resulting analysis shows Option 1 is the cheapest for Year 0 to Year 3.4. Option 3 is cheapest from Year 3.4 to Year 3.7. Option 2 is the cheapest past Year 3.7. Decision makers must take into account the likely life span for a given project, as this could greatly influence the outcome. This graph allows the user to determine the sensitivity of time effects in the analysis.

The breakeven lines shown in Figure 3 were developed using Equation 7 to calculate the EAC for each option for each period of comparison. For example, Option 2 EAC for a life span of one year is $21,400. When we increase the life span to two years, the EAC drops to $11,061.84. For three years, it is $7,621.03. As the projects are spread out over longer periods of time, the resulting EACs are generally smaller. As shown by Option 1, the EAC will not change if there is no initial capital cost. The EAC is equal to the recurring costs each year. When we plot the EACs for all options across a range of project life spans, we can see where one project becomes more expensive than the others. Simple spreadsheet commands will even return the exact point where the EACs intersect, as well as show the intersects graphically.

Validating DoD Cost Factors

The second area of methodology focuses on validating occupational illness cost factors created by the DoD in 1988. Most previously cited methodology estimates the direct and indirect cost of occupational illness by summing up what is spent to treat the illness and what is lost due to a person having the illness. Direct costs include medical expenses and disability payments. Indirect costs include forgone earnings, fringe benefits, home production, lost productivity, turnover, and retraining. The basic total illness cost equation is

$$\text{Total Cost} = \text{Direct Cost} + \text{Indirect Cost} \tag{8}$$

Equation 8 is the foundation of understanding occupational illness costs. We will develop refined methodology in later sections that modify this basic equation as needed.

As we develop specific methodology to quantify direct and indirect costs for Air Force personnel, we will continually adjust this basic form of the equation to arrive at the final model.

Direct Medical Costs.

While both medical and disability costs are considered to be direct costs, this research project will focus solely on medical costs. Disability costs are normally paid through the Department of Veterans Affairs, although there is some disability paid from the DoD in the early stages of compensation for a service member. We will not consider costs outside of the Department of Defense appropriations, particularly since the author is attempting to show the impact to an organization funded through DoD appropriations. Military medical expenses, consisting of military care and purchased care, were provided to the author through a contracted data retrieval service for the Air Force Surgeon General's (AF/SG) office. Medical cost data is available for 1999 through 2008 and is broken down into fiscal year, illness, rank, age group, gender, then year cost, and bed day or frequency, depending if the cost was due to hospitalization or an outpatient visit. It is important to note the medical cost data was provided in then year dollars. Then year dollars show the cost of care in the year care was provided. Just as we cannot compare the price of a loaf of bread from today with 30 years ago, we cannot compare medical expenses occurring in different years. We need to adjust all costs to a base year, or common year, so comparisons can be made. The following section addresses normalizing direct medical costs to overcome this problem.

Normalizing Direct Medical Costs.

Generally, the price of goods and services increase over time due to inflation. The Bureau of Labor Statistics (BLS) provides inflation factors for goods and services, allowing us to see the effects of inflation over time (bls.gov). One must normalize costs occurring in different years before any analysis can be done. For our purposes, normalization simply means adjusting costs from different time periods to a common time period to account for normal increases in prices over time. The Consumer Price Index will allow us to compare prices from different years and distinguish price increases due to inflation and price increases due to simply higher cost. Unfortunately, BLS does not provide a convenient tool for us to normalize medical costs, so we will create one.

SAF/FM has an online tool on the Air Force Portal to convert then-year dollars to base-year dollars. Unfortunately, the Air Force cost conversion tool does not help because of the unique nature of Defense Health Program (DHP) appropriations. DHP appropriations are a mix of Operations and Maintenance, Procurement, Personnel, and Research/Development/Testing dollars. There is no tool available to convert mixed appropriations.

To overcome the mixed nature of DHP appropriations, we used the Consumer Price Index – Medical (CPI-M) database (bls.gov). CPI-M measures the inflation of medical costs over time. Table 4 shows the CPI-M inflation data as well as the normal CPI inflation data for 1999 through 2008 (Ibid). We use these values to build an index allowing us to convert then-year medical costs to a base year value equal to the year 2008.

Table 4. CPI-M Base Year Conversion Factors (bls.gov).

Year	Medical CPI Index Value	Medical CPI Inflation Value	Traditional CPI Index Value	Traditional CPI Inflation Value	Medical CPI Normalization Factor
1998	238.1	-	162.0	-	-
1999	246.5	3.5%	164.7	1.7%	1.464
2000	255.6	3.7%	169.3	2.8%	1.412
2001	267.2	4.5%	175.6	3.7%	1.350
2002	279.8	4.7%	177.7	1.2%	1.289
2003	292.7	4.6%	182.6	2.8%	1.233
2004	303.8	3.8%	186.2	2.0%	1.188
2005	317.0	4.3%	191.7	3.0%	1.138
2006	329.8	4.0%	199.4	4.0%	1.094
2007	343.8	4.2%	203.6	2.1%	1.049
2008	360.8	4.9%	212.5	4.4%	1.000

The base year conversion index was built by dividing the CPI-M inflation factor obtained from the Bureau of Labor Statistics for 1999 through 2007 by the inflation factor for 2008. The BLS set 1984 as a base year equal to 100. Any increase or decrease in prices since 1984 will result in an increase or decrease from this base value of 100. For example, in Table 4, the inflation factors for years 1999 and 2008 are 246.5 and 360.8, respectively. We use Equation 9 to calculate the conversion factor to normalize then year costs to a given base year:

1 + ((Base Year Index Value – Then Year Index Value) / Then Year Index Value) (9)

To clearly demonstrate this formula, Equation 10 calculates the normalization factor for 1999:

$$1 + ((360.8 - 246.5) / 246.5) = 1.464 \quad (10)$$

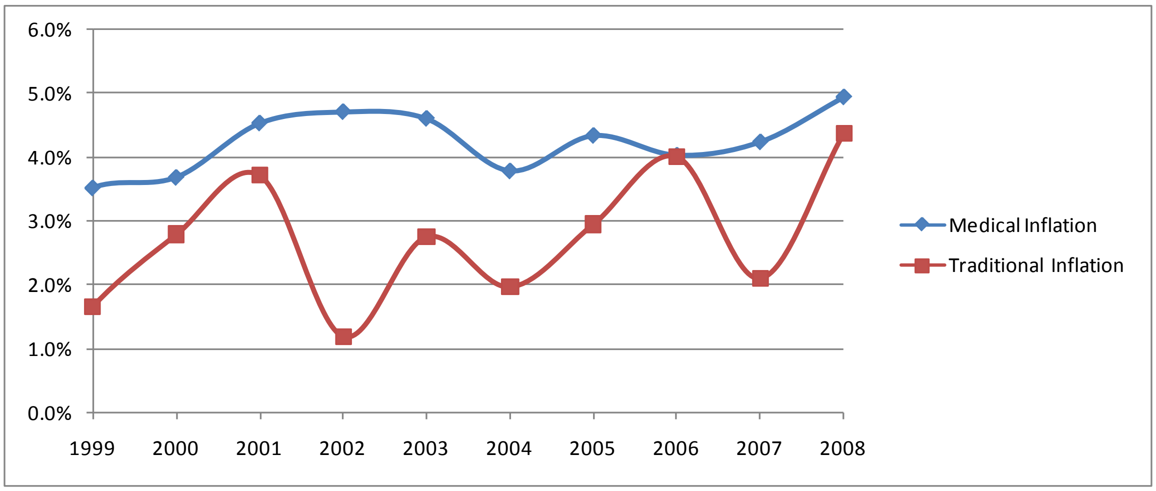
Normalization factors allow us to modify costs occurring in years 1999 through 2007 to a base year of 2008, as shown in Equation 11:

$$NDC = WCPIM * DC \quad (11)$$

where NDC is the normalized direct medical cost, WCPIM is the weighted CPI-M normalization factor and DC is the direct cost reported in then year dollars by AF/SG.

Table 4 and Figure 4 demonstrate the necessity of building a special conversion index for medical costs. The data and figure clearly shows that medical costs rise much faster than the traditional CPI index. Using the traditional CPI index instead of the CPI-M index would result in underestimating the normalized costs when converting to a 2008 base year.

Figure 4. Yearly Comparison of Medical and Traditional CPI Inflation (bls.gov).



Now that all costs are in a common base year of 2008 dollars, we can concentrate on what portion of the costs are due to occupational illness.

Mean Attributable Factors.

According to previous research cited in the literature review, Leigh et al, Markowitz et al and Steenland et al developed methodology to determine what portion of illnesses can be attributed to occupational exposure. The attributable factors are specific to each type or category of illness. Leigh determined the mean value of the attributable factor is appropriate to use for occupational illness estimations (Leigh, 2008). See Appendix A-1 for a complete list of all illnesses and mean attributable factors included in this project. Table 5 provides a subset of illnesses as an example. As shown below, we see that 5.5% of Pulmonary Tuberculosis cases may be the result of occupational exposure. All further occupational illness cost analysis in this thesis is founded upon the mean attributable factors developed by previous researchers.

Table 5. Abbreviated List of Illnesses, ICD Codes and Attributable Factors.

Illness	ICD-9	Mean Attributable Factor
Pulmonary Tuberculosis	011	5.5%
Lymphoid leukemia	204	1.8%
Parkinson's disease	332	2.0%
Hypertensive heart disease	402	7.5%
Chronic bronchitis	491	15%
Asthma	493	16%
Chronic hepatitis	571.4	0.8%
Chronic renal failure	585	11.4%
Mesothelioma	NA	100.0%

With mean attributable factors, we can estimate the portion of normalized direct medical costs resulting from occupational illness, as shown in Equation 12:

$$NOIDC = MAF * NDC \tag{12}$$

where NOIDC is the normalized occupational illness direct cost, MAF is the mean attributable factor, and NDC is the normalized direct cost calculated in Equation 11. For example, if there was $10,000 spent on care for Chronic Bronchitis in 2008, we can multiply the cost by the mean attributable factor for Chronic Bronchitis, 15% as shown in

Table 5. The result is $1,500, which is the portion of medical costs for Chronic Bronchitis theoretically resulting from occupational illness. Mean attributable factors are a critical component in the conversion of direct medical costs to occupational illness costs. The factors also apply to bed days and illness frequencies, as shown next.

Inpatient Versus Outpatient Medical Costs

The preceding methodology allows us to develop direct medical costs resulting from occupational illness. The available data also shows inpatient costs and ambulatory costs. Inpatient costs are the result of admittance to a medical treatment facility and will result in some number of bed days for a particular stay. Inpatient cases will be used to validate the hospitalization cost factor shown in DoDI 6055.07.

On the other hand, ambulatory medical costs result from an illness that may not be severe enough to admit the patient, such as a routine doctor appointment or "sick call". Ambulatory medical costs will be used to validate the no lost time cost factor shown in DoDI 6055.07. Ambulatory costs do not result in bed days. However, the data provided by AF/SG shows the frequency of each visit for the list of occupational illnesses shown in A-1 of the appendix.

The number of bed days and frequency of ambulatory visits will also be multiplied by the mean attributable factors. This step is necessary to properly analyze the modified direct cost of occupational illness with the resulting bed days or visits to a hospital.

No Lost Time Factor Validation

To validate the DoD cost factor for no lost time, we will perform a simple linear regression. We will regress the normalized occupational illness direct medical cost from

Equation 12 against the frequency of visits due to occupational illness. We will then compare the β_1 coefficient from the regression with the DoD cost factor to determine if there is a statistically significant difference between the two estimates, as shown below in Equation 13:

$$NOIDC = \beta_0 + \beta_1 FOI \qquad (13)$$

where NOIDC is the occupational illness direct cost from Equation 12, FOI is the frequency of illness visits due to occupational illness, and β_1 serves as the validation cost factor to compare with existing DoD information. The cost factors provided by DoD are 20 years old. As such, we will apply normalization factors using the same procedure discussed earlier to normalize the factors to a base year of 2008.

Modeling Indirect Costs of Occupational Illness.

Indirect costs may be modeled based on hospitalization medical costs and the DoD cost factor for hospitalization. According to DoDI 6055.07, the hospitalization factor represents total cost of illness. Remember from Equation 8 that total costs equal direct costs plus indirect costs. The factor developed in 1988 was $466 per day for enlisted and commissioned personnel. We will estimate the indirect portion using actual medical costs, bed days, and mean attributable factors. Equation 14 shows how indirect costs will be calculated:

$$OIIC = (BDOI * HCF) – NOIDC \qquad (14)$$

where OIIC is the occupational illness indirect cost, BDOI is the number of bed days for a patient due to occupational illness, HCF is the DoD hospitalization cost factor and NOIDC is the normalized occupational illness direct cost. The results for each observation allow us to have an indirect and direct cost value for each incidence of occupational illness. Now we can validate the DoD cost factor for hospitalization.

Hospitalization Cost Factor Validation

We must determine if the DoD cost factor is robust enough to capture direct medical costs and still have allocation remaining for indirect medical costs. If the results from Equation 14 are largely negative, we may be able to conclude the cost factor is not accurate enough to total costs, or even the direct portion of medical costs.

As shown in the literature review, indirect costs have been estimated to be as high as $6 to $53 per dollar of direct cost (WSES.com) or as low as $0.59 per dollar of direct cost (Leigh, 1997). Using Equation 15 we can create a new cost factor with the existing DoD cost factor and direct medical cost data. The new factor will allow us to compare the two existing indirect cost estimates and lend validity to one or the other, based on our results:

$$OIIC = \beta_0 + \beta_1 NOIDC + \varepsilon \qquad (15)$$

where OIIC is the occupational illness indirect cost from Equation 14, NOIDC is the direct cost resulting from occupational illness, and β_1 serves as our new indirect occupational illness cost factor estimate. The coefficient β_1 will represent the dollar amount of indirect costs that results from each dollar increase in direct costs. In the following sections, the author will normalize the data and perform the analysis, as well as discuss results.

IV. Data Analysis

Cost Comparison Tool

The data analysis for the cost comparison tool developed for Hill AFB bioenvironmental engineers is fairly straightforward. The analysis will be based on two scenarios the engineers provided as examples of current processes. The current process and results will be discussed and then compared with results obtained from using the new tool discussed in Chapter III.

Current Process

Bioenvironmental engineers conduct industrial hygiene visits to certain work centers on a recurring basis. Their job includes ensuring safe work practices are followed and ensuring workers are protected from occupational hazards. The commander directed engineers to evaluate one process for each work center while the engineers conduct industrial hygiene surveys. The engineers seek out one process that may be improved through a reduction in exposure to a hazard. The process improvement is typically justified by cost savings of time, material, or manpower. However, if the new process is more expensive even though it is safer, the proposal may not get funded.

To calculate the costs of existing and proposed processes, engineers developed a basic spreadsheet. The spreadsheet tracks expected cost savings and initial capital requirements. Engineers then compare this to the cost of keeping the existing process in place. Table 6 below shows an example of the analysis currently done at Hill AFB. The existing tool is a very simple process that compares costs and expected savings.

Table 6. Hill AFB Cost Comparison Tool, Example 1.

Office	Workplace	Cat:
571 AMXS/MXDPAA	A-10 Sheet Metal, Hanger 1	1

Activity Number	Activity	PPE Type	# In Use	Replacement Frequency Per Year	Unit Cost	Annual PPE Cost per Activity
1	Chemical stripping	Butyl Ruber Gloves	5	12	$ 12.00	$ 720
		3M Full Face air purifying	15	2	$ 275.00	$ 8,250
		3M Half Face air purifying	5	10	$ 15.00	$ 750
		3M P100 Particulate	15	2	$ 8.00	$ 240
		3M Multi-Gas/P100	5	10	$ 20.00	$ 1,000

Current Process	Subtotal	$ 10,960

Activity Number	Activity	Exam Type	Cost per Exam	Freq per year	Number of workers	Annual Exam Cost per Shop
1	Chemical stripping	Occ Physical	$ 400.00	1	15	$ 6,000

Current Process	Subtotal	$ 6,000
Current Process	Total	$ 16,960

Activity Number	Activity	Engineering Control	Estimated Cost	Total Estimated Engineering Cost
1	Chemical stripping	CNC Process	$ 1,000,000.00	$ 1,000,000

New Process	Total	$ 1,000,000

Projected Savings/Loss	($983,040)

For example, Table 6 is broken down into three major activities. The first two activities show the current process. The last activity shows the proposed process. Many cells of the spreadsheet were keyed in manually instead of using basic spreadsheet formulas to calculate subtotals. More manual processes introduce the likelihood of error. The new process is estimated at $1,000,000, while current processes cost $16,960. The difference between the two estimations is $938,040.

We suggest a simple solution for this problem. The engineers should utilize basic spreadsheet formulas to subtotal each item, showing all steps of calculations to allow outsiders to quickly ascertain the intent of the process. We also recommend utilizing the notes or comments function, allowing the end user to add clarification for each step in the cost/benefit analysis. Documentation is absolutely critical to ensure the analysis is done properly.

Whatever spreadsheet capabilities are employed to calculate costs and benefits, it seems inappropriate to compare the initial cost of a new process with the annual cost of the existing process. As shown, in Table 6, the cost of a new process is $1,000,000. We do not know if this is a onetime cost or a recurring cost. This information is critical to properly compare the new process with the current process, and could greatly influence the answer. Also, other options may be available with lower initial costs but higher recurring costs. We showed in Chapter III how a higher initial cost could ultimately be the cheaper option, based on the projected lifespan and other factors. Next, we will see how using a simple model and inputs for initial and recurring cost can make a cost/benefit analysis simple, effective, and very transparent for the decision maker.

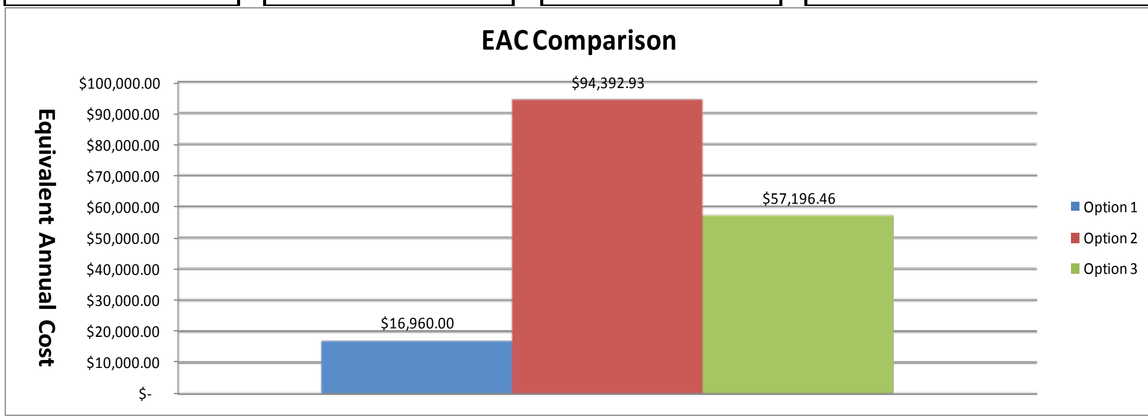
Validating Cost Comparison Tool

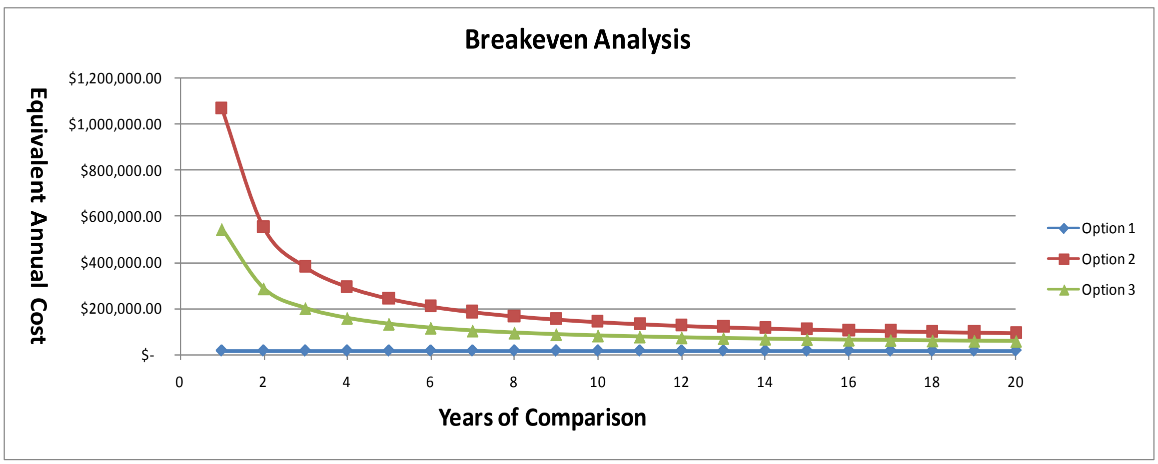
The following sections attempt to validate the new cost comparison tool demonstrated in the Methodology section by using it to analyze the analyses submitted by Hill AFB engineers. We start with validating the results of Table 6, where engineers concluded the new process would lead to expected losses of $983,040. Figure 5 below shows the new cost comparison tool in action, comparing the costs from an equivalent annual cost standpoint.

Figure 5. Validation of Cost Comparison Tool, Example 1.

Life Span (years)	20	Best Choice	Option 1	**ONLY CHANGE ITEMS HIGHLIGHTED IN YELLOW**		

Option 1		Option 2		Option 3		Breakeven Analysis		
Initial Cost	$ -	Initial Cost	$1,000,000.00	Initial Cost	$ 500,000.00	Option 1 versus Option 2	#######	years
Recurring Cost	$ 16,960.00	Recurring Cost	$ -	Recurring Cost	$ 10,000.00	Option 2 versus Option 3	#######	years
EAC	$ 16,960.00	EAC	$ 94,392.93	EAC	$ 57,196.46	Option 1 versus Option 3	#######	years





In this case, shown by Figure 5, the current process is cheaper even when the timeline is spread out to twenty years. The extremely high initial cost of the new process prohibits justification on a financial consideration alone. Option 3 is a hypothetical example, where the initial cost is half as much as the proposed option, with $10,000 recurring costs. This option is also prohibitively expensive. While the end results are the same as the engineers' analysis, the true cost differential per year is approximately $77,000 instead of the flat loss of over $980,000 reported earlier. The breakeven analysis fails to return a useful point of intersect, showing "###" because the annual costs never cross each other. Option 1 is always better than the others, within a realistic timeline.

The example in Table 7 shows another analysis conducted by Hill AFB engineers.

Table 7. Hill AFB Cost Comparison Tool, Example 2.

Activity Number	Activity	PPE Type	# used per year	Unit Cost	PPE Type	PPE Type	Annual PPE Cost per Activity	
2	noise/mechanical	Ear Plugs Disposable	500	$ 0.50			$ 250.00	
						Current Process	Subtotal	$ 250.00

Activity Number	Activity	Exam Type	Cost per Exam	Freq per year	Number of workers		Annual Exam Cost per Shop	
2	noise/mechanical	Occ Physical	$ 400.00	1	15		$ 6,000.00	
						Current Process	Subtotal	$ 6,000.00
						Current Process	Total	$ 6,250.00

Activity Number	Activity	Engineering Control		Estimated Cost	
2	pneumatic tools	Noise suppression device for air tools		$ 10,000.00	
	mech work	Rubber Isolation mounts		$ 5,000.00	
		Isolation barriers		$ 5,000.00	
			New Process	Total	$ 20,000.00
				Projected Savings/Loss	($13,750.00)

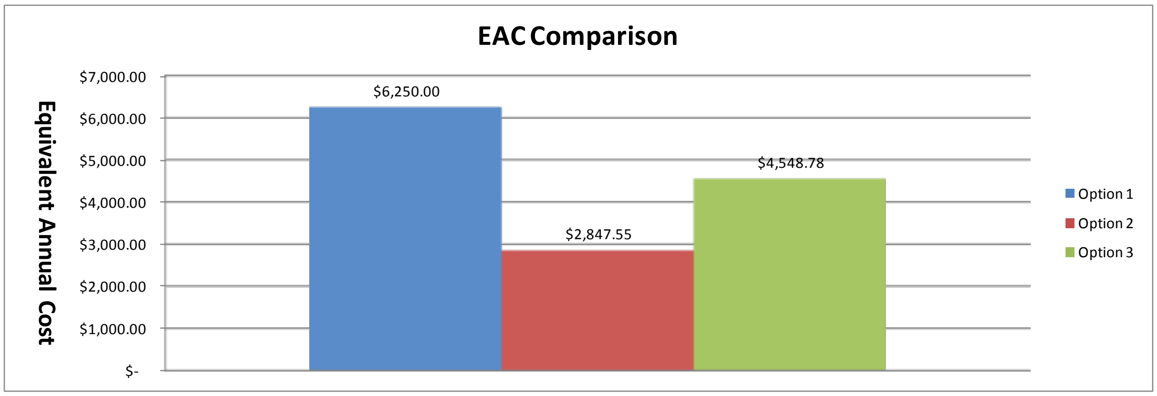
As we see in Table 7, the new process is estimated to be $13,750.00 more expensive than the current process. The upfront cost of the new equipment is compared directly with the ongoing cost of personal protective equipment and occupational physicals. This proposal is much more appropriate to compare as equivalent annual costs due to the higher fidelity and lower magnitude of the new process and its estimated costs.

Figure 6 clearly shows that although the current process is cheaper in the first year due to capital investment requirements, the new process becomes the best alternative financially as the initial investment is spread out over a realistic timeline. In this case, we chose 10 years for the lifespan of the equipment. Of course, actual timelines for equipment vary with use and care.

Figure 6. Validation of Cost Comparison Tool, Example 2.

Life Span (years)	10	Best Choice	Option 2	**ONLY CHANGE ITEMS HIGHLIGHTED IN YELLOW**	

Option 1		Option 2		Option 3		Breakeven Analysis		
Initial Cost	$ -	Initial Cost	$ 20,000.00	Initial Cost	$ 10,000.00	Option 1 versus Option 2	3.7	years
Recurring Cost	$ 6,250.00	Recurring Cost	$ -	Recurring Cost	$ 3,125.00	Option 2 versus Option 3	3.7	years
EAC	$ 6,250.00	EAC	$ 2,847.55	EAC	$ 4,548.78	Option 1 versus Option 3	3.7	years



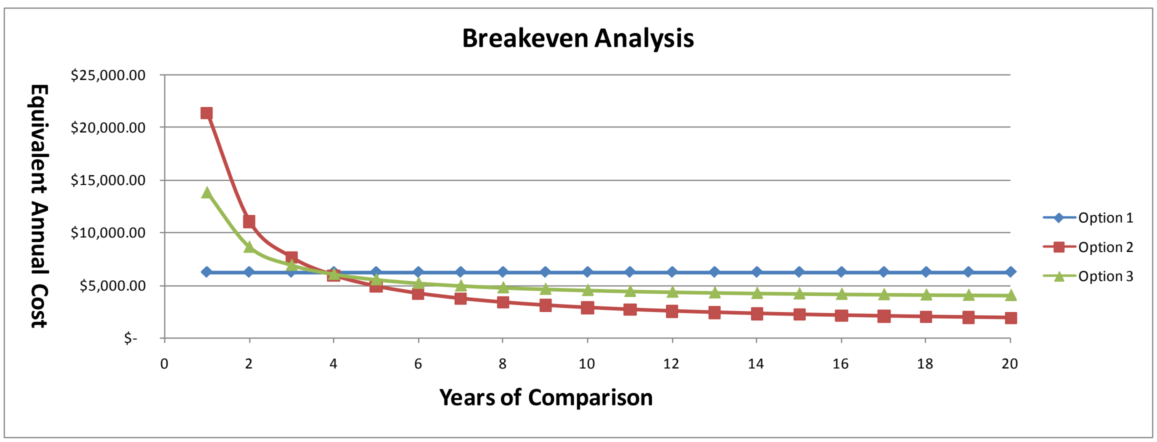


Figure 6 shows that the proposed option is clearly cheaper than the current process after 3.7 years. As long as the new equipment is expected to last 3.7 years or longer, the new process should be chosen over the existing process. This decision is purely financially driven, and the author acknowledges there may be other factors in the decision process. Option 3 is hypothetical, with half the required investment of Option 2 and half the required recurring costs of Option 1. This option is also financially better after 3.7 years.

Based on the two examples provided by Hill AFB engineers, we feel the proposed cost comparison tool, emphasizing equivalent annual cost and breakeven comparison, offers a much better analysis than the simple manual entry spreadsheet currently in use. We now direct our efforts to the DoD cost factor validation.

No Lost Time Cost Factor

To begin the data analysis, we will focus on the no lost time cost factor provided by the DoD in 1988. The no lost time factor represents the expected cost per occurrence of occupational illness. The cost factor was originally \$120 per day in 1988. We can easily adjust the factor to take into account normal cost growth for medical services, just as we did for the direct medical costs in Equation 9 from Ch III. Equation 16 shows the calculation:

$$\$120 * (1 + (360.8 - 134.4) / 134.4) = \$322.14 \tag{16}$$

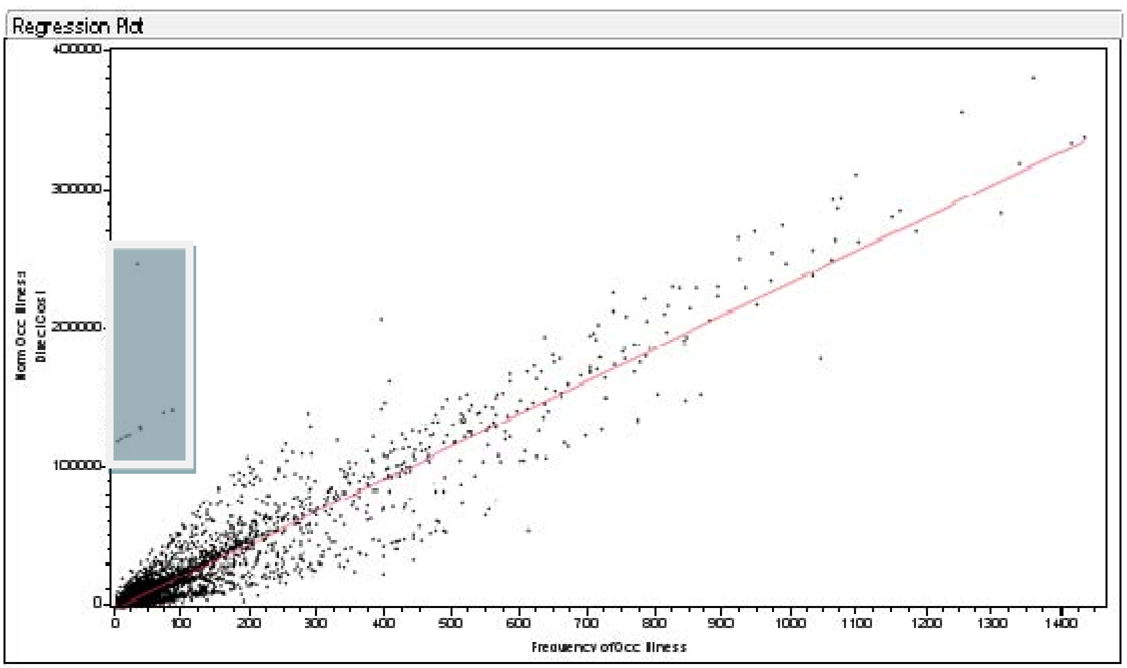
where \$120 is the cost factor in 1988, 360.8 is the CPI-M index value for 2008, and 134.4 is the CPI-M index value for 1988. From this calculation, we show that the DoD cost factor is \$322.14 when normalized to the year 2008. This normalized cost factor will be used throughout the data analysis for no lost time cases.

Military Care and Purchased Care Results

Now that the factor has been normalized, we will regress the number of occupational illnesses on the normalized occupational illness costs for ambulatory cases from FY1999 through FY2008. The resulting β_1 coefficient from the regression can then be compared to the normalized DoD cost factor. As noted in Equation 13, our regression equation is NOIDC = $\beta_0 + \beta_1$FOI + ε, where NOIDC is the normalized occupational illness direct cost and FOI is the frequency of occupational illness. The author uses JMP 7.0/8.0 and Stata 10 statistical software throughout the project.

As the initial regression results show, the model gives good indication that some type of singular cost factor for each occurrence is certainly possible. The model has an adjusted R^2 value of 0.887002, which simply means the model explains nearly 89% of all variance in the data. The dependent variable, normalized occupational illness cost, displays heteroskedasticity. Heteroskedasticity means non-constant variance. We can expect non-constant variance with medical costs, because each case will be greatly affected by many factors. Medical procedures for the same type and intensity of illness can vary based on where the treatment is provided, the skills and knowledge of the staff, and the actions of the patient. We address the heteroskedasticity and other diagnostics later.

Figure 7. Regression of Illness Costs on Frequencies, Military and Purchased Care.



The outliers shaded in dark gray are all due to Tinnitus cases all within the same year. The twelve data points fall outside the general linear relationship. Based on the hundreds of cases of Tinnitus and hearing loss in the data, we assume these cases do not represent relative cost/frequency ratio reliability that is shown by the rest of the model. However, we have inadequate case-level information that could justify excluding the cases. As such, we leave the outliers in place and note their existence in the regression. Table 8 shows the parametric estimates for the regression plot in Figure 7.

Table 8. Illness Costs/Frequencies, Military and Purchased Care.

Equation: NOIC = β0 + β1 FOI

Adjusted R square =	**0.887**	**N =**	**71,872**	
Variable	**Estimate**	**Standard Error**	**T Ratio**	**Probability**
Intercept	**-26.87**	**14.32**	**-1.88**	**0.0606**
Frequency of Occ Illness	**235.58**	**0.31**	**751.11**	**0.0000**

The results allow us to directly compare the DoD cost factor of $322.14 with the new cost factor based on actual medical cost data across 71,872 observations. The resulting regression coefficient of $235.58 is much less than $322.14. Although the t-statistic and adjusted R-square results show this model is reliable, we do not yet have enough information to invalidate the DoD factor.

The medical data contains cases where medical care was provided at a military treatment facility as well as purchased from non-military treatment facilities. Now, we will determine if there are any differences in the cost factor based on where the care was provided. We perform similar regressions grouping cases by whether or not the care was provided by a military facility.

Military Care Results

We can quickly manipulate the data to exclude observations where costs were incurred at non-military treatment facilities and regress the remaining 42,651 observations in the same manner as before. As shown in Figure 8, the results are largely similar, to include the outlying Tinnitus cases noted earlier.

Figure 8. Regression of Illness Costs on Illness Frequencies, Military Care.

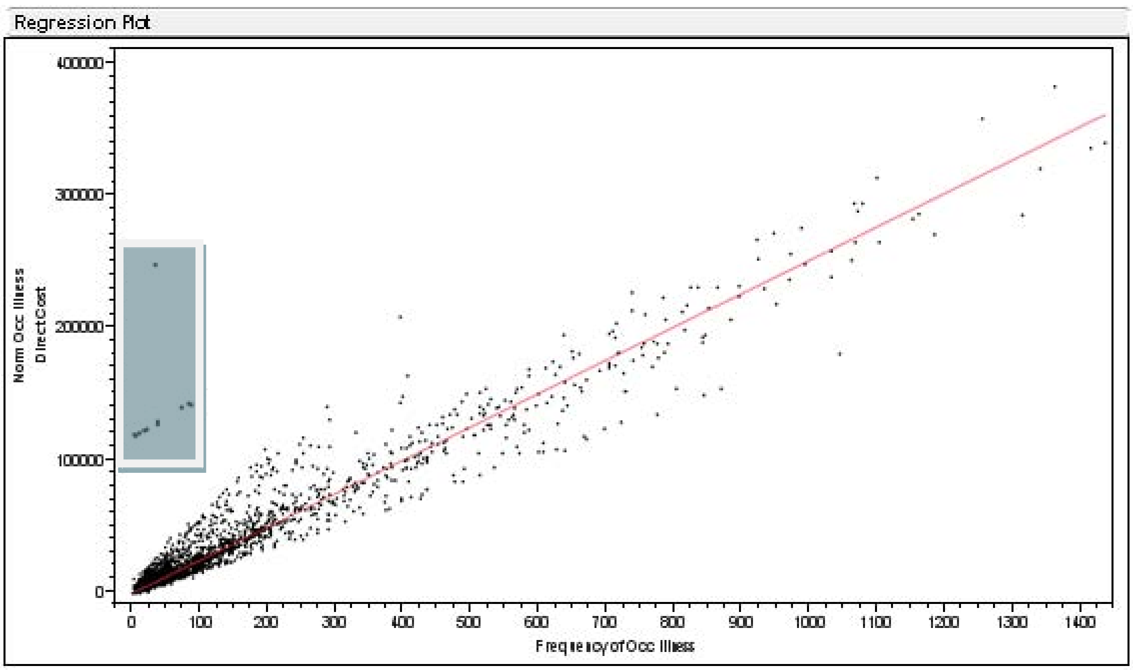


Table 9 below also shows promising results for the model. While the new cost factor is slightly higher than the previous cost factor, it is still below the DoD cost factor of $322.14.

Table 9. Parametric Estimates: Illness Costs on Illness Frequencies, Military Care.

Equation: NOIC = β0 + β1 FOI

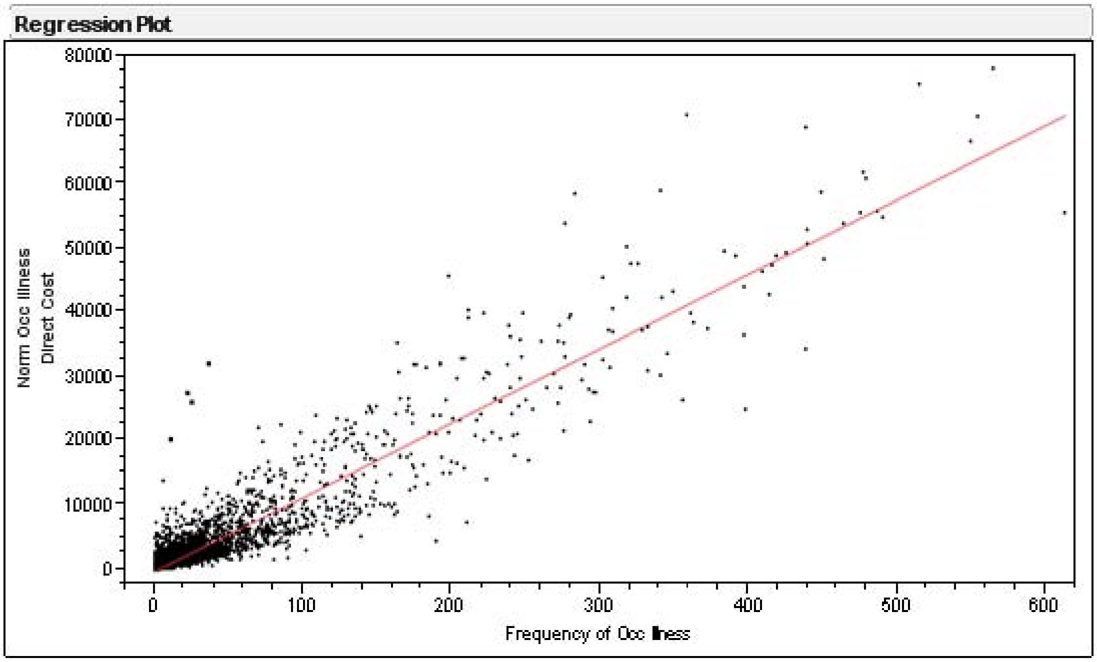
Adjusted R square =	0.921	N =	42,651	
Variable	**Estimate**	**Standard Error**	**T Ratio**	**Probability**
Intercept	**258.87**	**19.78**	**13.09**	**<0.0001**
Frequency of Occ Illness	**251.59**	**0.36**	**705.63**	**0.0000**

The intercept and frequency are both statistically significant, as shown by the high t-stats. One might argue for forcing the regression through the origin, because with no illness, there should be no cost. However, there will always be some cost of healthcare, with or without patients. Also, the variable is statistically significant, so we will leave it in place. Now, we will perform similar actions with only the observations resulting from purchased care to see if there is much difference.

Purchased Care Results

The results of observations where medical costs were incurred from non-military treatment facilities differ significantly. The differences are not evident from the regression plot below in Figure 9, as the model clearly demonstrates a similarly linear relationship with few outliers.

Figure 9. Regression of Illness Costs on Illness Frequencies, Purchased Care.



In this case, the outliers had no discernable pattern of illness or other factors. Some people's care will obviously cost more than others. Such is the dilemma of analyzing medical cost data.

Table 10 shows the parametric results for the regression of purchased care and frequencies of occupational illness. Note the much lower cost factor of $115.47 compared to the normalized DoD cost factor of $322.14. Also, this factor is much lower than the direct care costs incurred at a military treatment facility. There is strong explanation of variance, with an adjusted R-square value of 0.89 across 28,843 observations.

Table 10. Parametric Estimates: Illness Costs on Illness Frequencies, Purchased Care.

Equation: NOIC = β0 + β1 FOI

Adjusted R square = 0.890 N = 28,843

Variable	Estimate	Standard Error	T Ratio	Probability
Intercept	-9.70	6.05	-1.60	0.1089
Frequency of Occ Illness	115.47	0.24	483.21	0.0000

The previous regressions show a wide range of cost factors compared with the established DoD cost factor for no lost time. It may be of little use to develop a cost factor for each demographic group and illness. The results would be cumbersome and would likely not be used for rough order of magnitude (ROM) estimates. However, if we can show the existing cost factor is accurate across 74 specific illnesses, we feel the combined factor will be more useful for medical cost estimations. If we find the existing DoD cost factor is inaccurate, we will propose an updated factor for DoD to take under consideration.

Cost Factor Comparison

Table 11 recaps the cost factors to this point. We will compare the resulting factors in order to recommend the best factor for the DoD to use when estimating medical costs of occupational illness resulting in no lost time.

Table 11. Costs Factor Comparison.

Cost Factor	Value	Intercept	Adjusted R Square
DoD	$322.14	NA	NA
Military and Purchased Care	$235.58	-26.87	0.887
Military Care	$251.59	258.87	0.921
Purchased Care	$115.47	-9.70	0.890

Table 11 shows that all three models developed in this project have high explanation of variance, as noted by the adjusted R-square values. The combined military and purchased care regression resulted in a statistically insignificant intercept. Also, the frequency of military care versus purchased care is approximately 2 to 1, meaning active duty members are twice as likely to receive care at a military treatment facility as at a civilian treatment facility.

The likelihood of direct care or purchased care may also have much to do with geographical location and type of illness. Some military treatment facilities have been closed, outsourcing most or all care to the local community. For example, the Air Force Academy recently closed emergency services and inpatient services, forcing patients to go downtown for care (Press, 2008). Some military treatment facilities do not have the specialty care necessary in some instances, and refer patients off base for specialized care. Again, the Air Force Academy can be used as an anecdotal example based on the author's personal experience.

The combined military and purchased care factor is $235.58 per day, with an extremely tight confidence interval. Based on the standard error of 0.31 obtained in the regression, the 95% confidence interval is $234.97 to $236.20. Once we determine the confidence interval, we can properly compare the new factor with the existing DoD factor. If the DoD factor falls outside this confidence interval, we conclude that the DoD factor is statistically significantly different. Of course, it is obvious $322.14 does not fall between $234.97 and $236.20, so we conclude the DoD cost factor overestimates the direct medical cost of ambulatory visits based on our data set of over 71,000 observations across all ranks, genders, and age groups for the last 10 years. We further conclude the

DoD should adopt a new cost factor of $235.58, rounded up to $236 for ease of calculations, for no lost time medical cost estimation.

Now that we have decided on a final model, we will run two regression diagnostic tests. The first test will determine the normality of the dependent variable, normalized occupational illness cost. The second test will check for heteroskedasticity.

Normality checks for a data set of 70,000 plus observations are challenging. Some statistical software packages and computer systems simply cannot handle the task. We used the Shapiro-Wilk test and the histogram function in Stata 10. Appendix A19 shows the normality results. To summarize, the normalized occupational illness costs are not from a normal distribution. This is not surprising considering the data manipulation required to get to the values used in the regression.

In the heteroskedasticity check, we plotted the residuals against the predicted values for the regression equation. The cone shaped scatter plot in A20 notes moderate heteroskedasticity. To overcome this, we regressed the same equation with robust standard errors. The results of this regression can also be found in A20. The most significant change is to the standard errors. Otherwise, the cost factor remains unchanged.

Hospitalization Cost Factor

Now the research shifts to validate the DoD cost factor for hospitalization. This factor is much more complicated, because it attempts to estimate direct and indirect costs that may happen as a result of military or purchased care.

Following the same normalization process as Equation 16, the DoD cost factor of $466 is normalized to $1,250.99 in 2008 base year dollars. This normalized cost factor is the estimated cost per bed day for an occupational illness, to include direct and indirect costs. We will refer to this factor as a total cost factor because the total cost of illness includes direct and indirect costs. In order to divide the total cost factor into direct and indirect components, we will utilize the medical cost data for hospitalizations for active duty Air Force personnel from 1999 to 2008. The total cost per bed day, normalized to 2008 dollars, multiplied by the number of bed days will be the total cost of illness. The direct costs from the medical cost data will then be subtracted to leave only those costs supposedly due to indirect costs. The methodology of the calculations was laid out earlier in Equation 14.

Negative Indirect Costs

Preliminary analysis of the hospitalization data revealed a serious problem. Total costs are supposed to encompass direct and indirect costs. However, based on the 3,983 observations of inpatient medical expenses from 1999 to 2008, the vast majority of reported expenses outstripped the DoD total cost factor estimate. In other words, the DoD "total" cost factor was not high enough to cover the direct medical expenses, let alone indirect costs associated with occupational illness. Table 12 shows the preliminary analysis of negative indirect illness costs.

Table 12. Percentages of Negative Indirect Illness Costs.

	Total Observations	Negative Observations	Percentage
Purchased Care	2,346	1,799	76.7%
Military Care	1,637	1,578	96.4%
Total	3,983	3,377	84.8%

Table 12 clearly demonstrates the vast majority of hospitalizations over the past 10 years cannot be accurately estimated by the DoD total cost factor. The DoD total cost factor seems inaccurate to model the actual medical expenses without having any left over to consider true indirect costs such as employee turnover, lower productivity, and costs to society in general. Purchased care costs surpassed the DoD estimates in 1,799 of the 2,346 observations, or 76.7% of the time. Military care costs surpassed the DoD estimates in 1,578 of the 1,637 observations, or 96.4% of the time. This again leads to an interesting situation where purchased care seems less expensive than military care. Finally, aggregating the data, 3,377 of the 3,983 total observations, or 84.8% of the cases were higher than DoD total cost factors would predict.

DoD Cost Factor Invalidation

The DoD total cost factor for hospitalization is supposed to estimate total costs: direct medical costs plus some amount of indirect costs. Existing indirect cost estimates range from $0.59 to $53 per dollar of direct cost, as noted in earlier chapters. While we cannot say which end of the spectrum is more appropriate, we can say with certainty that the indirect costs are not negative. The DoD total cost factor is not valid on the basis that it does not adequately capture even the direct medical costs of occupational illness. One cannot regress the data as proposed in Equation 15 when the dependent variable is predominantly negative.

Proposed DoD Cost Factor Update

Based on the invalid DoD cost factor, we cannot use the existing data to determine an occupational illness indirect cost factor. However, we can update the DoD total cost factor for direct medical costs only. As such, the planning factor for DoD cost estimating should be displayed in a manner that analysts fully understand that no indirect costs are included in the estimating factor. To be clear, the DoD total cost factor for hospitalization should be renamed to the DoD direct medical cost factor for hospitalization.

The process for determining a valid direct medical cost factor is fairly straightforward. In fact, we will follow closely with the methodology used for validating the DoD no lost time cost factor. Instead of using the frequency of occupational illness, we will use the bed days resulting from occupational illness. Otherwise, the steps in both analyses are comparable. We will proceed by considering all treatment observations, military care and purchased care. Then, we will separate the two categories to see if there is any marked difference. Finally, we will recommend a new DoD cost factor to estimate direct medical expenses.

Military and Purchased Care

We have a total of 3,983 observations of medical costs incurred as the result of hospitalization of active duty Air Force members from 1999 to 2008. The reason for hospitalization is due to a primary diagnosis of the illnesses included in Appendix A-1. The regression equation is:

$$\text{NOIC} = \beta_0 + \beta_1 \text{BDOI} + \varepsilon \tag{17}$$

where NOIC is the normalized occupational illness medical cost and BDOI is the number of bed days resulting from occupational illness. The resulting regression scatter plot and statistics show the relationship between cost and bed days.

Figure 10. Regression of Military and Purchased Hospitalization Costs on Bed Days

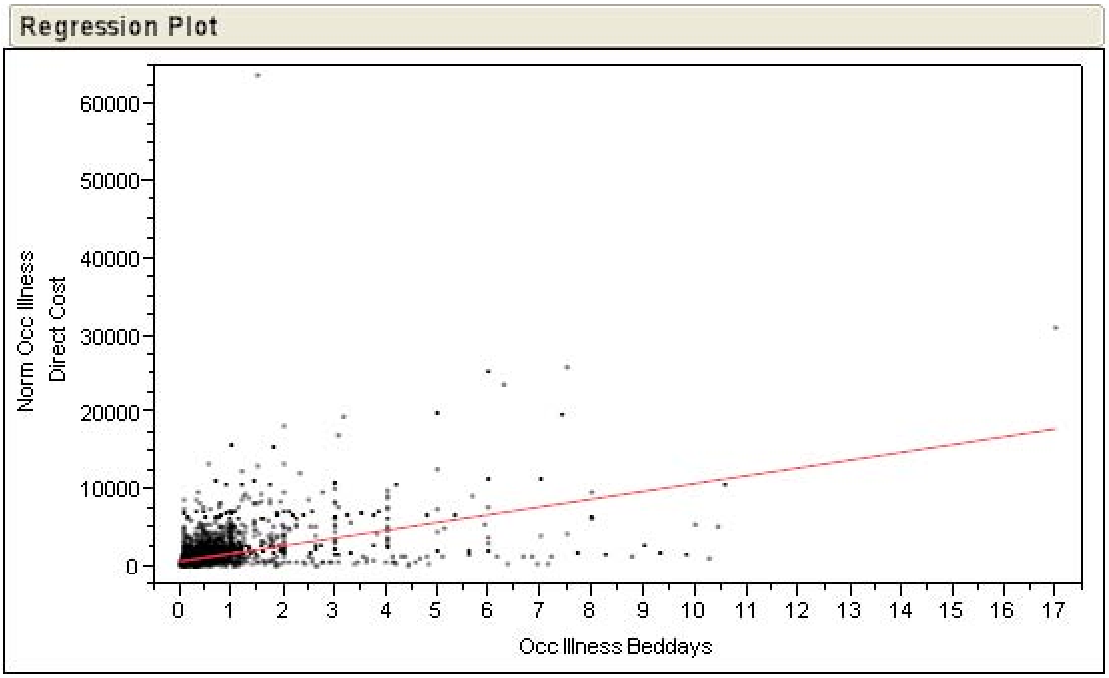


Figure 10 shows a simple linear regression of combined military and purchased medical care costs on bed days, both attributed to occupational illness. While both the intercept and bed days variables are statistically significant, as shown in Table 13, the adjusted R-square of 0.214 does not bode well for the initial model.

Table 13. Initial Total Cost Factor Validation.

Equation: NOIC = β0 + β1 BDOI

Adjusted R square =	**0.214**	**N =**	**3,982**	
Variable	**Estimate**	**Standard Error**	**T Ratio**	**Probability**
Intercept	**774.18**	**33.12**	**23.37**	**<0.0001**
Bed Days from Occ Illness	**1005.55**	**30.54**	**32.92**	**<0.0001**

In Table 13, the beta coefficient for bed days due to occupational illness is $1,005.55. This tells us that for each additional bed day, the occupational illness cost will increase by $1,005.55. Remember back to our normalized DoD total cost factor of $1,250.99.

The regression results show a factor that is lower by $245.44. It is tempting to consider this difference as the elusive indirect costs we sought earlier, as demonstrated by Equation 14. However, the model is misspecified at this point and any regression results at this point would be inaccurate. Perhaps the bed days do not explain enough of the variance in medical costs. While we do not have individual level data for medical costs, we do have some additional demographic indicators. Next, the model will be augmented by more independent variables in an attempt to better explain variance.

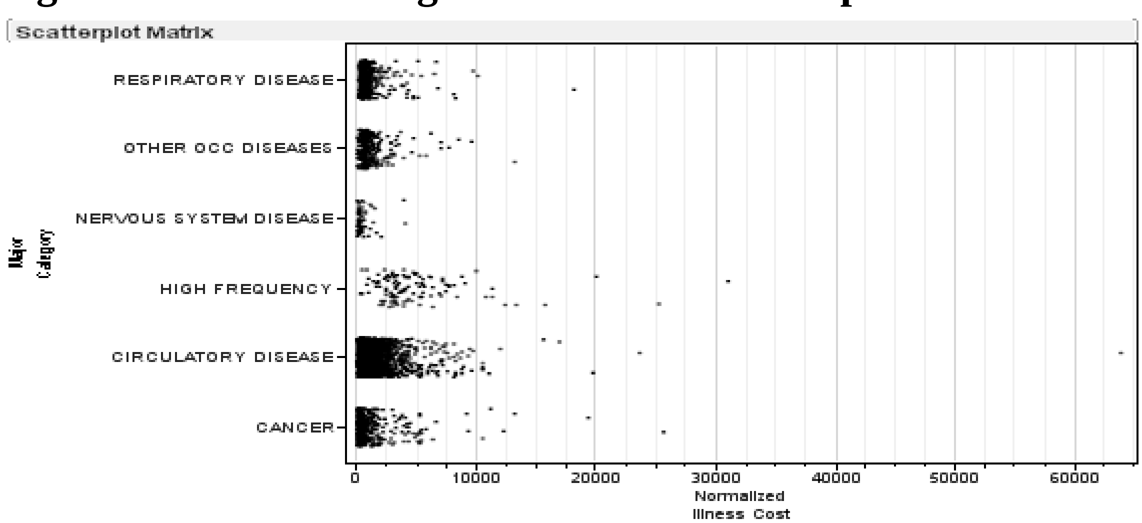
One approach is to include all possible variables in an equation to see if anything is statistically significant. The so-called "kitchen sink" approach relies on results of statistical software versus forethought and theoretical modeling (Wikipedia). Once all variables are included, the model is reduced down to statistically significant variables. The problem with this approach is that model misspecification may occur through inclusion of irrelevant variables, simply for the sake of including whatever data is available. We feel we should make use of available data, provided the model is grounded in theory.

The data structure allows us to consider whether certain diseases may behave differently in terms of accruing costs. We are able to aggregate the list found in A1 into six broad categories: respiratory diseases, cancer, circulatory diseases, high frequency diseases, nervous system diseases, and "other" occupational diseases. The "other" category simply contains illnesses attributable to occupational exposure but not otherwise fitting into the other five categories. It is possible one illness category drastically influences the results. We can run regressions including only a specific category or excluding the category. Additionally, we can break out occurrences into purchased care or military care. The table in A2 summarizes the regression results from the aforementioned possibilities. Out of the 39 simple linear regressions, only a few produced somewhat promising results as noted by the adjusted R-square value. For nearly every category, purchased care resulted in a much lower bed day coefficient, and adjusted R-square value as well. Clearly, these models do not convey the results we hoped for, either.

Data Appearance

Looking at the raw data can provide much useful information. Consider the following figures, showing a three dimensional cube of illness category, occupational illness cost, and occupational illness bed days. Figure 11 shows a "cube" from the statistical software package, JMP 8.0. The figure allows us to quickly determine if there are any notable relationships between the major category of illness and cost or bed days. If one illness category stands out or does not behave as the others, we may need to explain the variation before proceeding. Figure 11 shows how the categories of illness differ in the spread of occupational illness costs.

Figure 11. Illness Categories and Cost Scatterplot.



As shown above, the distribution and variance of costs differ somewhat between categories of illness when military and purchased care observations are combined. Nervous system disease appears to have fewer observations than the other categories. Otherwise, the categories all follow similar patterns: many observations clustered in the lower cost range, with sporadic outlying observations at extreme cost levels.

A similar figure in the appendix, A3, shows a graph for all observations substituting bed days for cost. Graphs A4 through A7 display the same concept but breaking out military care and purchased care separately. Looking at A3 through A7, we see the spread of bed days among the categories of illness are similar as well. One notable difference between military care and purchased care is that the costs for purchased care seem to be a much tighter distribution at the lower levels than military care. A possible explanation of this stems from the military healthcare billing system. As active duty patients are cared for in non-military treatment facilities, the charges for the care are mostly predetermined by agreements for care through the Tricare insurance program. Fees for procedures are mostly agreed upon through memorandums of understanding, which allow the providers to be in a Tricare network. The insurance billing resembles "flat rate" billing as opposed to what a civilian counterpart would be charged for the same visit. Otherwise, no readily apparent differences exist in the data.

ROM Hospitalization Model Specification

Based on our conclusion that there are no discernible differences between the illness categories or source of care, we do not have reason to divide the data or create separate cost factors. We submit the results contained in Table 13 stand as our updated DoD Direct Medical Cost Factor. Admittedly, a single cost factor developed from the limited direct medical cost data available is not optimal. We provide rationale for the low explanation of variance, or low R-square value, obtained in our final model. The variance of occupational illness cost depends on other factors besides bed days; data we simply do not have access to in order to refine our model specifications. The model can be used as a heuristic approach in order to gain a rough order of magnitude for direct medical costs. The model is still unable to account for indirect medical costs. However, the existing choices of indirect medical cost factors may still apply. The decision maker must determine which end of the spectrum to use, ranging from $0.59 to $53.00 per dollar of direct medical costs.

Parsimony Versus Specificity

One intent of this research project was to provide a clean, versatile cost per bed day factor. The factor should apply across all variables: age, gender, rank, source of treatment, disease, and number of bed days. However, based on the previous heuristic modeling approach, such an endeavor to create a single robust cost factor is nearly impossible. We would expect high resistance against a model where we controlled for all variables. The model would not be very useful for rough order of magnitude cost estimating, which we believe is the basic intent of the DoD cost factors.

Although the following modeling analysis will hardly be convenient as a direct medical cost estimation tool, we will use all the data at our disposal and attempt to provide a more complete approach. The final model specification is complex, but so is the nature of occupational illness. We feel costs differ depending on the age of the patient. We feel costs differ based on the specific or general type of disease in question.

What this new model loses in convenience, it gains in explaining significantly more of the variation of our earlier model.

In addition to using demographic variables and specific diseases, we tried using a log-level model specification. Logarithmic transformation of the dependent variable is helpful because it can compress the range of costs normally experienced in our data set. We also set aside the occupational illness attributable factors to see if normalized cost would lead to better results. Each of these options was used across military care, purchased care, and a combination of military and purchased care. Finally, we used major disease categories, minor categories, sub minor categories, and specific disease lists. The final model is a result of nearly two hundred iterations before arriving at the optimal solution.

Equation 18 shows the final model specification, with the regression results following. The full list of diseases included in the disease vector can be found in the Appendix, A-8.

$$NOIC = \beta_0 + \beta_1 OIBD + \beta_2 Age + \beta_3 Diseases_i \qquad (18)$$

where NOIC is the normalized occupational illness cost, OIBD is the number of bed days resulting from occupational illness, Age is a continuous age variable, and $Diseases_i$ is an x_i vector of 25 specific illnesses listed in Appendix A-8. These 25 illnesses were the statistically significant illnesses out of a list of over 200.

The final model performed well when only military care observations were used. This reduced our number of observations from 3,983 to 1,637. However, the high adjusted R-square value of .7080 provides some assurance this was the correct course of action. When purchased care or combined purchased/military care observations were included, the explanation of variance fell by nearly half to .3559 and .3502, respectively. As expected, bed days and age were statistically significant, as were the 25 illnesses referenced earlier.

It is important to consider the results within the proper context. The list of diseases originally requested from AF/SG was based on existing literature regarding occupational illness. The results show that some diseases cost more or less, by a statistically significant amount, than others. We acknowledge our results are based solely on the disease set in our database. It is likely another data set of illnesses would produce differing results. The take-away note here is that illnesses are unique and complex. Attempting to model “illness” creates an overly parsimonious model with no true estimation validity beyond ease of use, which is a poor measure of effectiveness.

Regression Diagnostics

Throughout the many iterations of the final regression model, we performed basic diagnostics. We focused mainly on normality and heteroskedasticity. Since we attempted to use three different dependent variables over all observations, military care observations, and purchased care observations, we have a total of nine combinations to check for normality and heteroskedasticity. Normality checks show if the dependent variable comes from a normal distribution. In all cases, the goodness of fit test rejected the null hypothesis that the data comes from a normal distribution. See the diagnostic results in A9 through A17 for specific values. Our results were especially surprising for the logarithmic transformation of costs. The histogram appears highly normalized for each case, although the goodness of fit test still fails.

Heteroskedasticity is non-constant variance, which is a violation of basic ordinary least squares (OLS) assumptions. "Heteroskedasticity does not cause OLS coefficient estimates to be biased. However, the variance (and, thus, standard errors) of the coefficients tends to be underestimated, inflating t-scores and sometimes making insignificant variables appear to be statistically significant (Wikipedia)." We checked for heteroskedasticity by plotting the residuals against the predicted values for each version of observation class and dependent variable. The resulting nine checks for heteroskedasticity are also contained in the Appendix in A9 through A17. The log-transformed data did not appear heteroskedastic, but the others did.

We chose normalized occupational illness cost as our final dependent variable. This dependent variable displayed heteroskedasticity. To overcome this, we used robust standard errors. The coefficients do not change, but the standard errors are compensated to account for the bias mentioned earlier. No variables dropped from our equation when computing the robust standard errors. See Appendix A18 for the updated regression estimates. The model specification remains unchanged and the robust standard errors are provided to show we acknowledged and compensated for heteroskedasticity.

Now that the data has been analyzed, we continue our discussion of the results and provide some recommendations for the decision maker. We also point out some limitations in our research efforts and offer areas of further research.

V. Discussion

Conclusion

Given the erratic nature of medical cost inflation, we initially theorized the DoD cost factors would have understated the actual costs shown in our data. However, the DoD no lost time factor seems to be overstated by 27% compared to our revised no lost time factor. Also, the DoD hospitalization factor seems to be overstated by 20% compared to our revised no lost time factor. It is possible the CPI-M index does not apply accurately to military treatment costs as it does to purchased treatment costs. Also, the lack of continuity within DoD hampers our understanding of how the original cost factors were developed. It would greatly enhance our analysis if we knew the factors, data, steps, theories, and logic used in the creation of those factors.

As we conclude this research endeavor, we must discuss limitations, recommendations, and further research. Limitations include data collection problems, understanding causes and courses of treatment for illnesses, and organizational challenges. We recommend the use of our tools and factors developed within this research effort. Finally, we provide several recommendations of future research opportunities, both to add to the progress made here and to break into new areas of concentration. First, consider the limitations we faced in this project.

Limitations

Any research project is sure to bring about a number of limitations. This project is no exception. There are issues with data, timeframes, responsibility, oversight, communication, privacy, and the inherent complex nature of occupational illnesses. While each of these limitations causes considerable problems on its own, the culmination of limitations imposes a substantial challenge to adequately analyzing and modeling illness costs in the Air Force.

Data Limitations

Data availability is extremely limited when researching occupational illness. The civilian sector has mandated reporting of occupational injuries and illnesses to the Department of Labor (DoL). The Bureau of Labor Statistics (BLS) then makes the highly detailed data available via the internet. However, federal agencies are not required to submit injury and illness data to the DoL. DoD civilian employee data is eventually rolled up and reported to BLS, but the aggregated numbers do not differentiate between illness and injury. Private sector data is presented in great detail, providing specific case rates and occurrences for most injuries or illnesses. With a few clicks, one is able to obtain days away from work, rates of illness incidence, fatalities, and much more for a wide range of occupations in the U.S (bls.gov).

Illness data for Active Duty Air Force personnel is a little tougher to obtain.

The Defense Medical Epidemiology Database (DMED) provides case rates and occurrences of any injury or illness associated with an ICD-9 code. However, there is no way to confirm whether the injury or illness was a result of occupational exposure. To overcome this problem, researchers have developed attributable factors to determine what percent of a particular illness would likely be caused by occupational illness. However, the incidence rates of the most costly illnesses (cancers, respiratory diseases, etc) are extremely low. These categories of occupational illnesses usually manifest themselves decades after exposure. Relatively speaking, the short twenty-year tenure of a full-career

Air Force member does not provide the length of observation needed to capture a large portion of most occupational illnesses, especially the most expensive ones.

In addition to the illness data challenges for Air Force military and civilian employees, there are problems with obtaining the actual direct cost data for medical expenses. Actual expenses are tied to actual cases. It is difficult to obtain costs for an illness without accessing databases containing personal information on patients. Thankfully for patients, but unfortunately for researchers, cost information is extremely difficult to get. Institutional Review Board (IRB) protocols must be established to ensure proper use and disposition of any medical information, even though the cost information by itself is non-identifying.

Illness Timelines

Timeframes associated with occupational illness were touched on briefly, but warrant further discussion. Occupational illness can be very small and simple, such as a case of contact dermatitis caused by repeated exposure to a paint thinner solution. Illnesses can also be very large and complex, such as mesothelioma caused by inhalation of dust in an asbestos tile factory. Or, consider a case where a bartender is exposed to second hand smoke for years and develops lung cancer. Determining the exact cause, time, and place someone became ill is not easy. Many illnesses occur years, even decades, after a person is exposed to a chemical, dust, fumes, et cetera. Illnesses can be a result of many variables: exposure, genetic propensity for illness, health, diet, and diligence in adhering to safe work practices, just to name a few. The expansive spectrum of possible factors plays a major role in how long it takes a person to develop an occupational illness.

Organizational Challenges

Responsibility, oversight, and communication are related concerns or barriers to effective occupational illness analysis. Short personnel tenures and even shorter budget cycles do not promote long-term planning and intervention policies, particularly at the unit level. Funding for occupational health initiatives usually comes from the Operations and Maintenance (O&M) budget. Some costs (direct medical expenses) for occupational illnesses come from Defense Health Program (DHP) money, a completely separate "pot of money" within the DoD. Other direct medical costs are recouped from unit funds, such as when civilian workers file a worker's compensation claim as a result of workplace illness or injury. Disability payments from more serious illnesses come from the Department of Veteran Affairs (VA), yet another appropriation outside the DoD. Commanders are duly concerned about the health and welfare of the workforce. Even so, there are very few tangible benefits to investing resources in occupational health beyond basic regulatory requirements.

Indirect costs and benefits may be more interesting to commanders as long as we can properly quantify them. Productivity, morale, and turnover all impact the mission. As noted in previous sections, turnover costs for civilians are absorbed at local levels. Turnover/training costs for military personnel occur at differing levels of Air Force appropriations or commands, such as the Personnel and O&M appropriations within the Air Education and Training Command. Productivity and morale impact the mission, but are generally unquantifiable as a service-wide application. Productivity for a fighter unit is likely to differ significantly from productivity at a maintenance unit. Services squadrons throughout the Air Force may have differing measures of productivity than a

Contracting squadron. Associating costs to loss of productivity would have to occur at a local level, negating the ability to roll up costs into a broader model. Finally, morale would need to be measured through individual surveys over time. Evaluating morale and assigning indirect costs is complex enough to be a research project of its own.

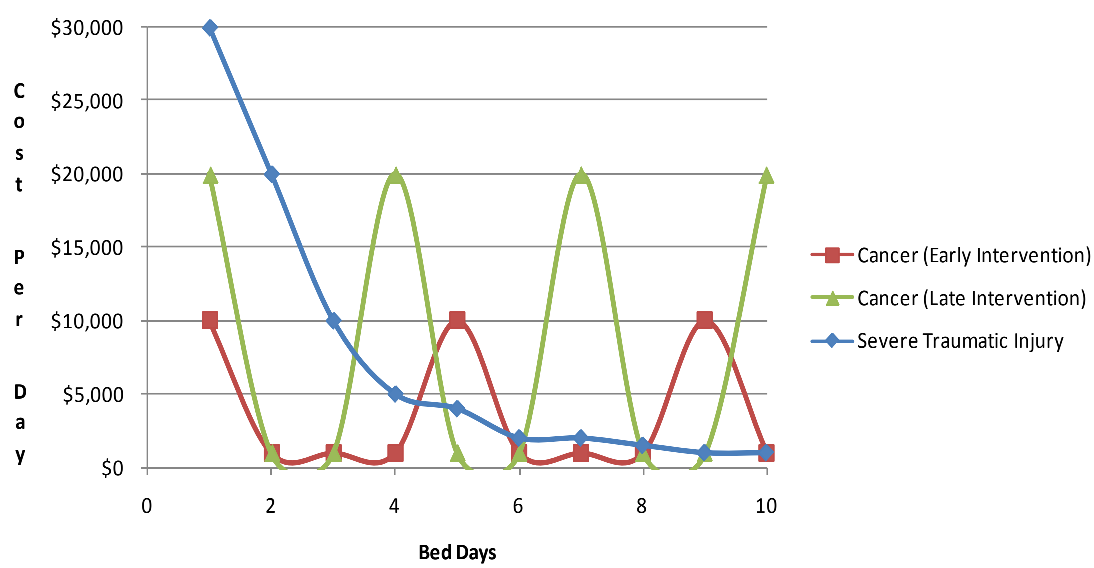
Illness Cost Profiles

Illnesses follow general profiles for course of treatment, depending on the type of illness and patient demographics (McCoy, 2008). Differing courses of treatment lead to unique cost profiles. For instance, a cancer patient may become hospitalized and receive chemotherapy sessions at predetermined times during the hospitalization. Occupational illness costs incurred due to cancer in this instance would be fairly consistent, on average, across the hospitalization. Some bed days would result in low costs from observation and basic sustenance. Other days would result in much higher costs from the chemotherapy. Trauma patients normally have high initial costs from surgery or emergency care. Follow-on bed days for observation and recuperation may result in fewer costs per bed day.

Illness cost profiles also change depending on when the illness is discovered and treated. The later the illness is discovered, the more costly the intervention becomes (Ibid). For this reason, it may not be realistic to model each illness specifically. Based on the available data, cancer is generally more expensive per bed day than tinnitus. However, there are cases where tinnitus is more expensive per bed day, likely due to the severity and timeframe of onset to treatment. Yet, total costs of cancer may be higher based on the length of treatment.

Courses of treatment for similar diseases may differ, based on the protocol of the treatment facility, access to equipment and skilled personnel, and differing costs of medical care across the country. In fact, the cost of health care can drastically change the interpretation of medical cost data. Dr. J. Paul Leigh excluded two high-cost markets; specifically, he excluded California and New York (Leigh, 1992). Including these much higher-priced markets may skew the results and can certainly affect a cost per illness or cost per bed day factor. Our data set did not indicate the geographic location of costs incurred. Some graphic examples of how costs may be incurred for various diseases across a timeframe are shown in Figure 12 below. The data used is arbitrary and is only for the purpose of demonstrating how illness profiles may affect cost (McCoy, 2008). As we discussed earlier, costs may occur at different times during a hospitalization depending on the injury/illness, course of treatment, and severity of injury/illness.

Figure 12. Injury/Illness Cost Profile Examples.



Note in the above figure, severe traumatic injury costs per day are very high, but gradually get lower as the patient may stabilize and move into recovery/observation. Cancer costs may follow an oscillating wave profile, with higher costs incurred on chemotherapy treatment days and recovery/observation on other days. The onset, type, and severity of the cancer may drastically alter the peaks of the costs, again shown in Figure 12.

Recommendations

The author makes several recommendations as part of this research effort. Based on the aforementioned results from the cost comparison tool and the regression results, 75th AMDS personnel should implement the new tool to enhance the effectiveness of their occupational health project comparisons. The engineers should not limit the use of the cost comparison tool to industrial hygiene visits. We recommend the tool be used to analyze any significant capital outlay, or when determining which course of action may be financially better over various timeframes and costs. We also recommend avoiding manual data entry into spreadsheets whenever possible. Formulas provide transparency and validity to spreadsheets by allowing analysts to see exactly how the calculations are being made. Notes/comments should also be used to provide more continuity.

Additional recommendations involve the data collection, reporting, and analysis of occupational illness of active duty Air Force members. Data repositories should be integrated to allow easier comparison of direct medical costs with occupational illness occurrence. Services should also seek to capture occupational illness-related disability payments made by other agencies, such as the VA. Although the costs do not impact service budgets, per se, the understanding of the magnitude of costs may influence decision makers when evaluating potential occupational health expenditures. Ideally, analysis at higher federal budgetary levels may result in allowing cross-appropriation funding for occupational health projects, with the goal of spending fewer dollars now to prevent larger costs in the future.

We recommend the Department of Defense adopt our updated cost factors for illnesses resulting in no lost time. We recognize the factors are based solely on Air Force data. However, the fact that the factors have not been updated in 20 years is cause for concern, especially if planners are using this information to allot taxpayer dollars for medical expenses.

Further Research

Opportunities for further research include quantifying an indirect cost, such as employee turnover. We encountered significant challenges linking employee discharge with occupational illness. Modeling one component of indirect costs would greatly improve our understanding of the magnitude of total illness costs. Better communication and buy-in with organizations in charge of such data may improve the likelihood of future research in this area.

Other research efforts should be directed at comparing direct medical costs across services. The DoD cost factors may have been built upon data from all services. However, lack of information from the DoD prevents us from understanding the methodology behind the cost factors. Accurately planning direct medical costs at DoD level requires access to direct medical costs from all services, regardless of who takes on the research project to update the factors.

Occupational illness is a challenging subject to research. However, the cost savings implications of finding a better way of business provide excellent incentive for further study. To start, successful research requires organizational support and access to data. It also requires an understanding of the importance of occupational illness analysis and mitigation beyond dollars and cents. We applaud those individuals we met during this research effort who, on a daily basis, attempt to understand the problems and craft solutions for occupational illness issues.

Appendix

A1. List of Occupational Illnesses, ICD-9 Codes, and Attributable Factors.

Illness	ICD-9	Mean Attributable Factor
Malignant neoplasm of nasopharynx	147	36.0%
Malignant neoplasm of liver/bile ducts	155	0.8%
Malignant neoplasm of nasal cavities	160	39.5%
Malignant neoplasm of larynx	161	10.5%
Malignant neoplasm of trachea/bronchus/lung	162	9.7%
Malignant melanoma of skin	172	3.8%
Malignant neoplasm of bladder	188	11.0%
Malignant neoplasm of kidney	189	1.2%
Lymphoid leukemia	204	1.8%
Myeloid leukemia	205	1.8%
Monocytic leukemia	206	1.8%
Other specified leukemia	207	1.8%
Leukemia of unspecified cell type	208	1.8%
Toxic encephalitis	323.7	2.0%
Other cerebral degenerations	331	2.0%
Parkinson's disease	332	2.0%
Other specified hemiplegia and hemiparesis	349.82	2.0%
Hereditary/idiopathic peripheral neuropathy	356	2.0%
Polyneuropathy due to other toxic agents	357.7	2.0%
Toxic myopathy	359.4	2.0%
Hearing Loss Due to Noise	388.12	100%
Tinnitus	388.3	100%
Tinnitus, no other symptoms	388.30	100%
Subjective Tinnitus	388.31	100%
Objective Tinnitus	388.32	100%
Contact Dermititis and other eczema	692	100%
Bachache, no other symptoms	724.5	100%
Carpal Tunnel Syndrome	354.0	100%
Essential hypertension	401	7.5%
Hypertensive heart disease	402	7.5%
Hypertensive renal disease	403	7.5%

A1 (Cont.). List of Occupational Illnesses, ICD-9 Codes, and Attributable Factors.

Illness	ICD-9	Mean Attributable Factor
Hypertensive heart and renal disease	404	7.5%
Acute myocardial infarction	410	7.5%
Acute/subacute ischemic heart disease	411	7.5%
Old myocardial infarction	412	7.5%
Angina pectoris	413	7.5%
Other forms of chronic ischemic heart disease	414	7.5%
Subarachnoid hemorrhage	430	7.5%
Intracerebral hemorrhage	431	7.5%
Other and unspecified intracranial hemorrhage	432	7.5%
Occlusion and stenosis of precerebral arteries	433	7.5%
Occlusion of cerebral arteries	434	7.5%
Transient cerebral ischemia	435	7.5%
Acute, but ill-defined, cerebrovascular disease	436	7.5%
Other and ill-defined cerebrovascular disease	437	7.5%
Late effects of cerebrovascular disease	438	7.5%
Atherosclerosis	440	7.5%
Bronchitis, not specified as acute or chronic	490	15%
Chronic bronchitis	491	15%
Emphysema	492	15%
Asthma	493	16%
Bronchiectasis	494	15%
Extrinsic allergic alveolitis	495	15%
Chronic airway obstruction, not elsewhere classified	496	15%
Coal workers' pneumoconiosis	500	100%
Asbestosis	501	100%
Pneumoconiosis due to other silica or silicates	502	100%
Pneumoconiosis due to inhalation of other dust	503	100%
Pneumoconiosis due to other inorganic dust	504	100%
Pneumoconiosis, unspecified	505	100%
Respiratory conditions due to chemical fumes and va	506	100%
Pulmonary Tuberculosis	011	5.5%

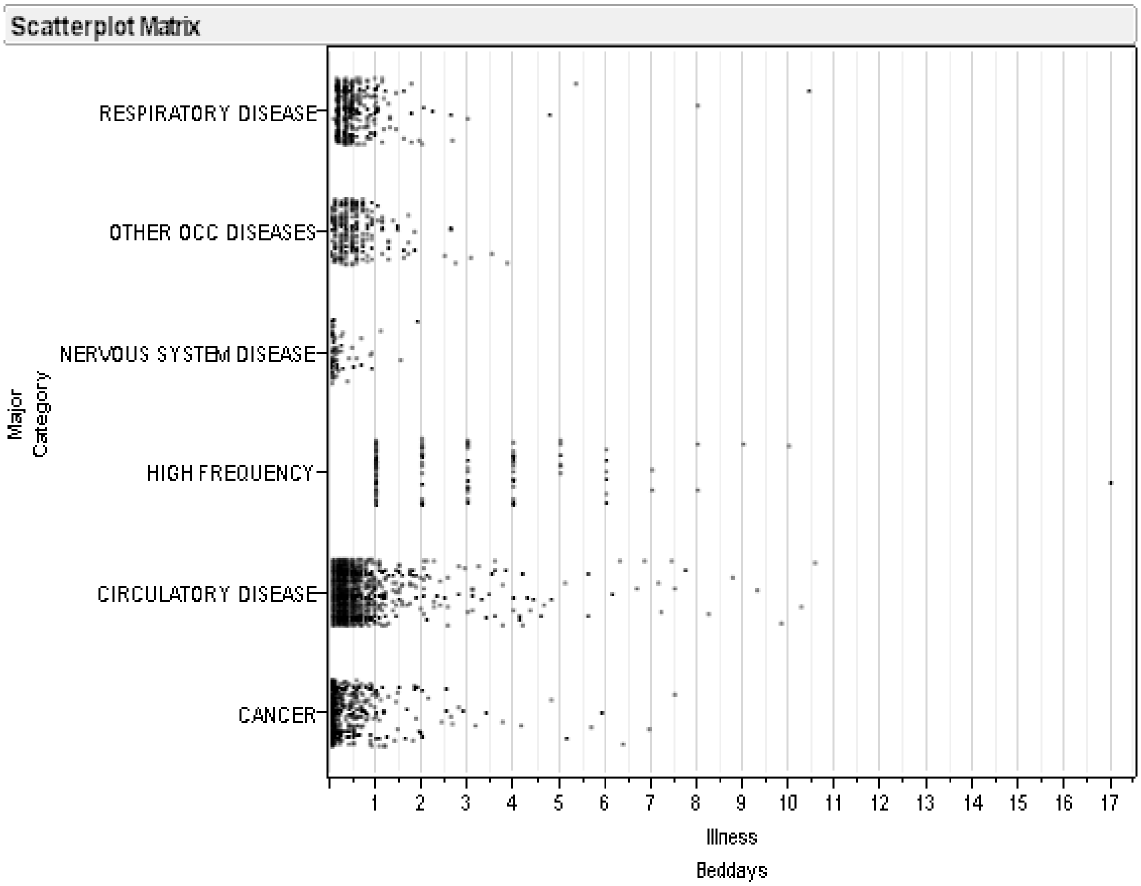
A1 (Cont.). List of Occupational Illnesses, ICD-9 Codes, and Attributable Factors.

Illness	ICD-9	Mean Attributable Factor
Mesothelioma	NA	100%
Chronic hepatitis	571.4	0.8%
Cirrhosis of liver without mention of alcohol	571.5	0.8%
Unspecified chronic liver disease	571.9	0.8%
Acute glomerulonephritis	580	11.4%
Nephrotic syndrome	581	11.4%
chronic glomerulonephritis	582	11.4%
Nephritis and nephropathy, unspecified	583	11.4%
Acute renal failure	584	11.4%
Chronic renal failure	585	11.4%
Renal failure, unspecified	586	11.4%
Renal sclerosis, unspecified	587	11.4%

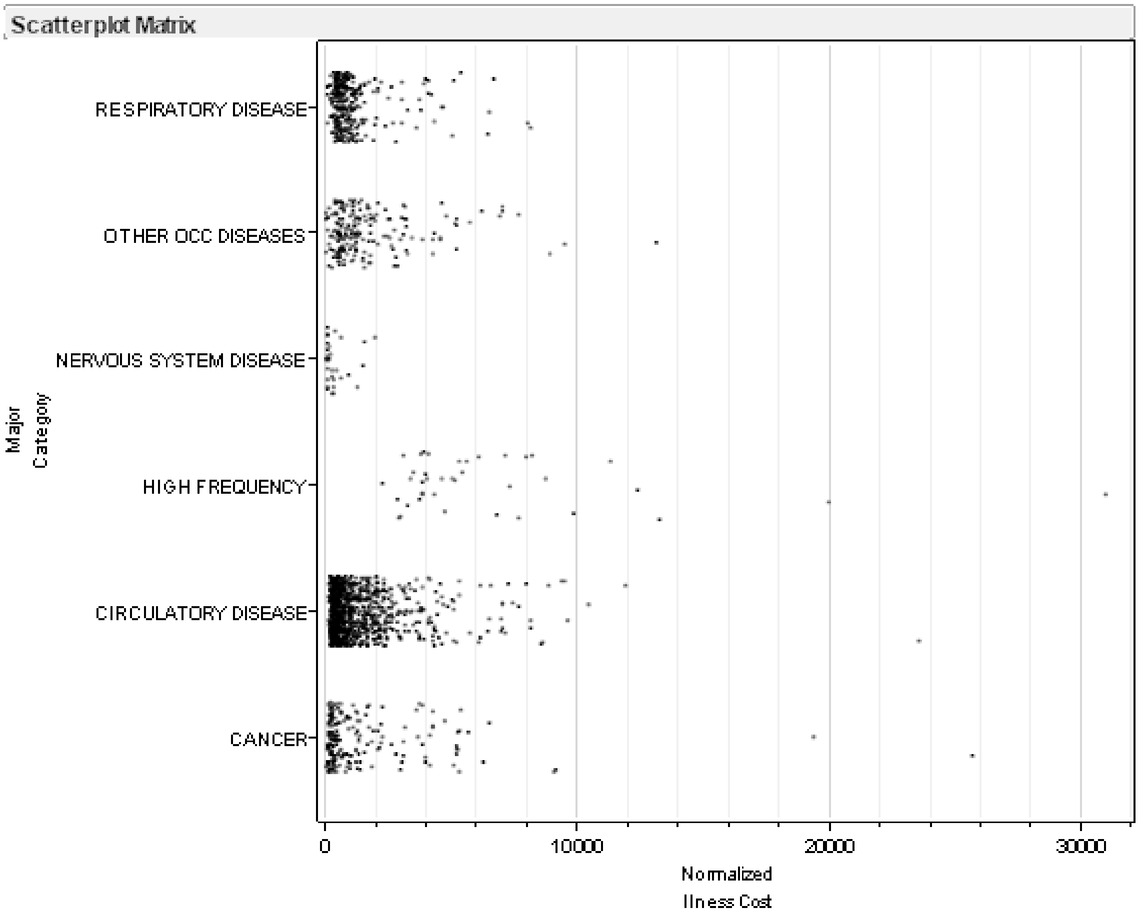
A2. Regression Matrix of Hospitalization Cost Factor Model Variations.

Illnesses	All Observations		Military Care		Purchased Care	
	Bed Day Coefficient	Adjusted R-Square	Bed Day Coefficient	Adjusted R-Square	Bed Day Coefficient	Adjusted R-Square
All	$ 1,005.55	0.214	$ 1,912.28	0.568	$ 614.48	0.096
Exclude High Frequency	$ 857.43	0.127	$ 2,063.84	0.460	$ 518.28	0.057
Exclude Cancer	$ 978.82	0.208	$ 1,821.85	0.550	$ 640.78	0.103
Exclude Respiratory Disease	$ 1,005.25	0.210	$ 1,912.28	0.568	$ 587.92	0.089
Exclude Circulatory Disease	$ 1,268.72	0.421	$ 1,759.86	0.629	$ 850.12	0.265
Exclude Nervous System Disease	$ 1,001.83	0.212	$ 1,907.61	0.567	$ 610.07	0.095
Exclude Other Illnesses	$ 990.07	0.210	$ 1,915.60	0.579	$ 603.70	0.093
Include Only High Frequency	$ 993.93	0.290	$ 1,525.80	0.666	$ 549.21	0.085
Include Only Cancer	$ 1,241.48	0.263	$ 2,443.23	0.675	$ 314.16	0.028
Include Only Respiratory Disease	$ 1,011.85	0.282	$ 875.59	0.290	$ 1,268.79	0.306
Include Only Circulatory Disease	$ 705.00	0.082	$ 3,177.06	0.568	$ 477.92	0.046
Include Only Nervouse System Disease	$ 1,667.99	0.664	$ 2,275.78	0.681	$ 1,652.27	0.686
Include Only Other Illnesses	$ 1,666.72	0.373	$ 1,842.52	0.393	$ 1,512.38	0.474

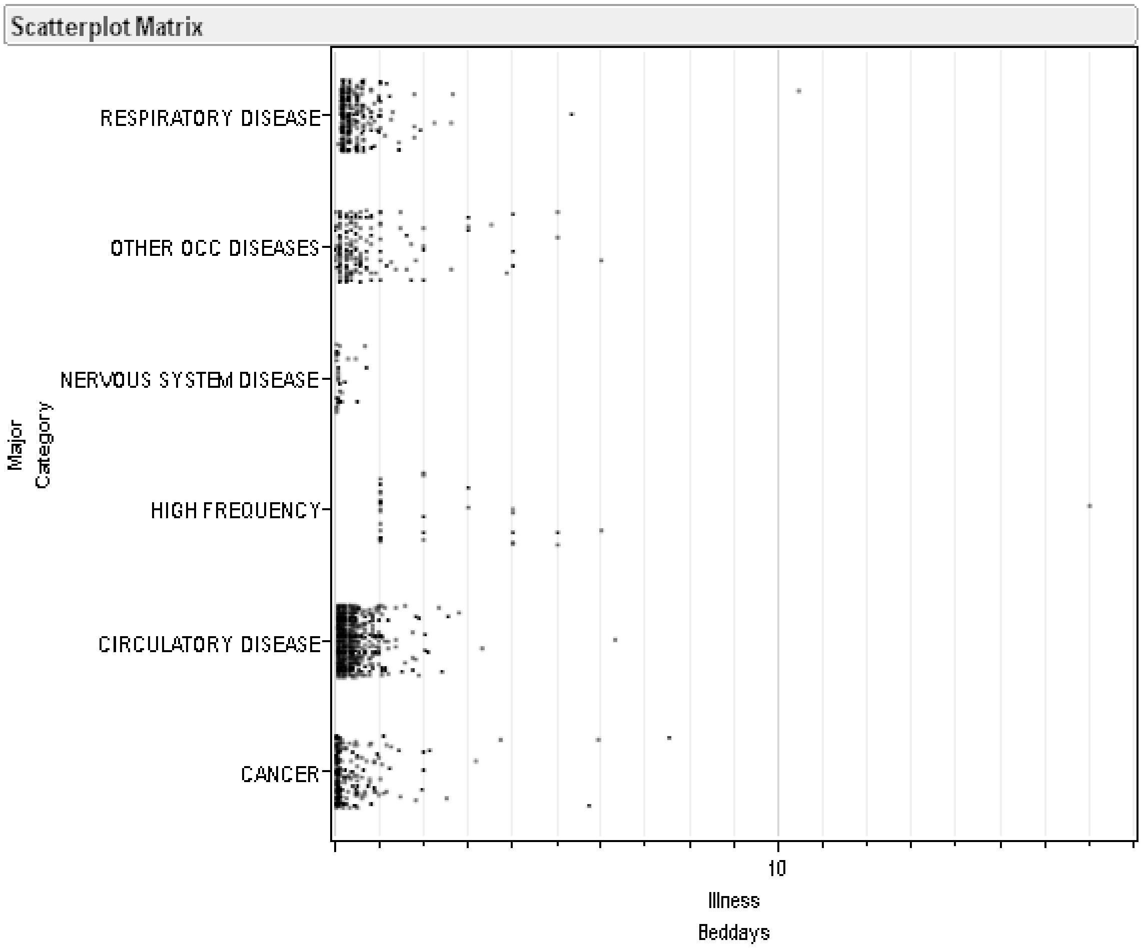
A3. Scatterplot of All Hospitalizations: Disease Category and Bed Days



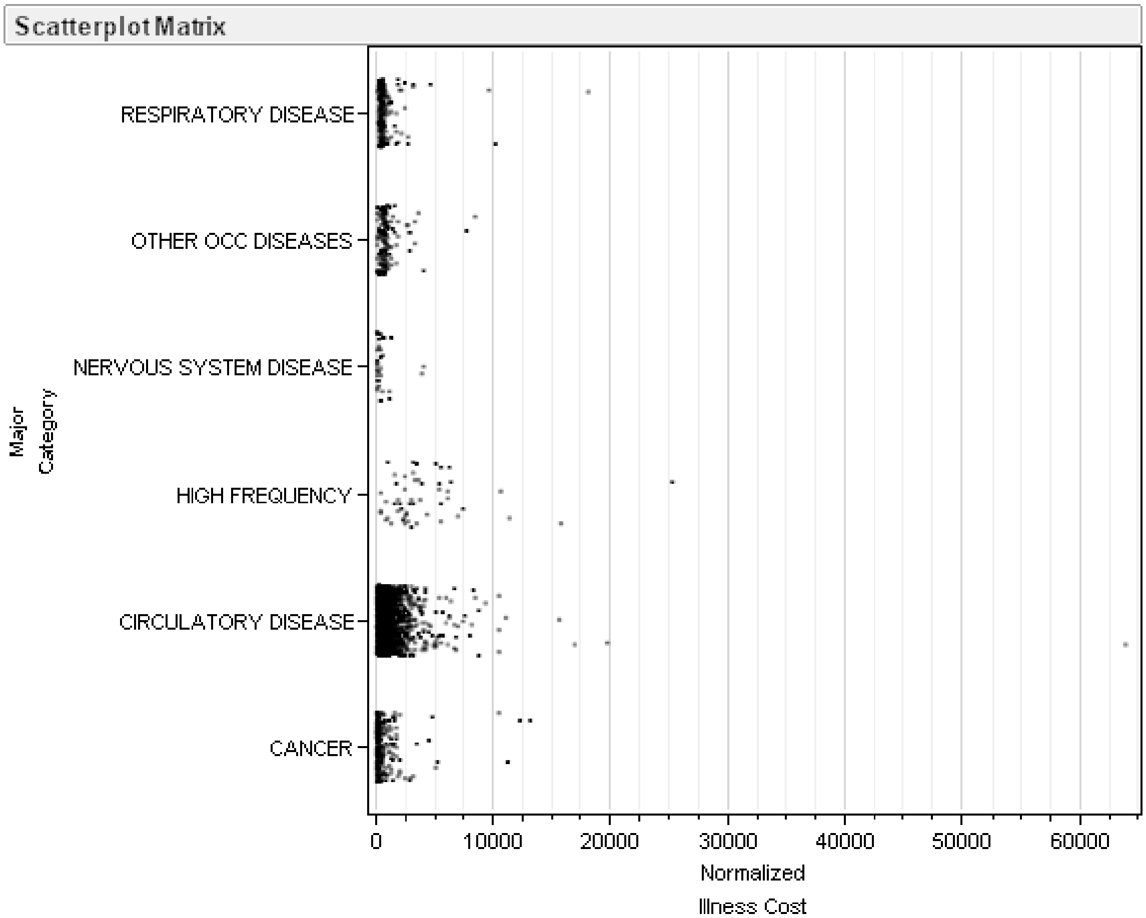
A4. Scatterplot of Military Care Observations: Disease Category and Illness Cost



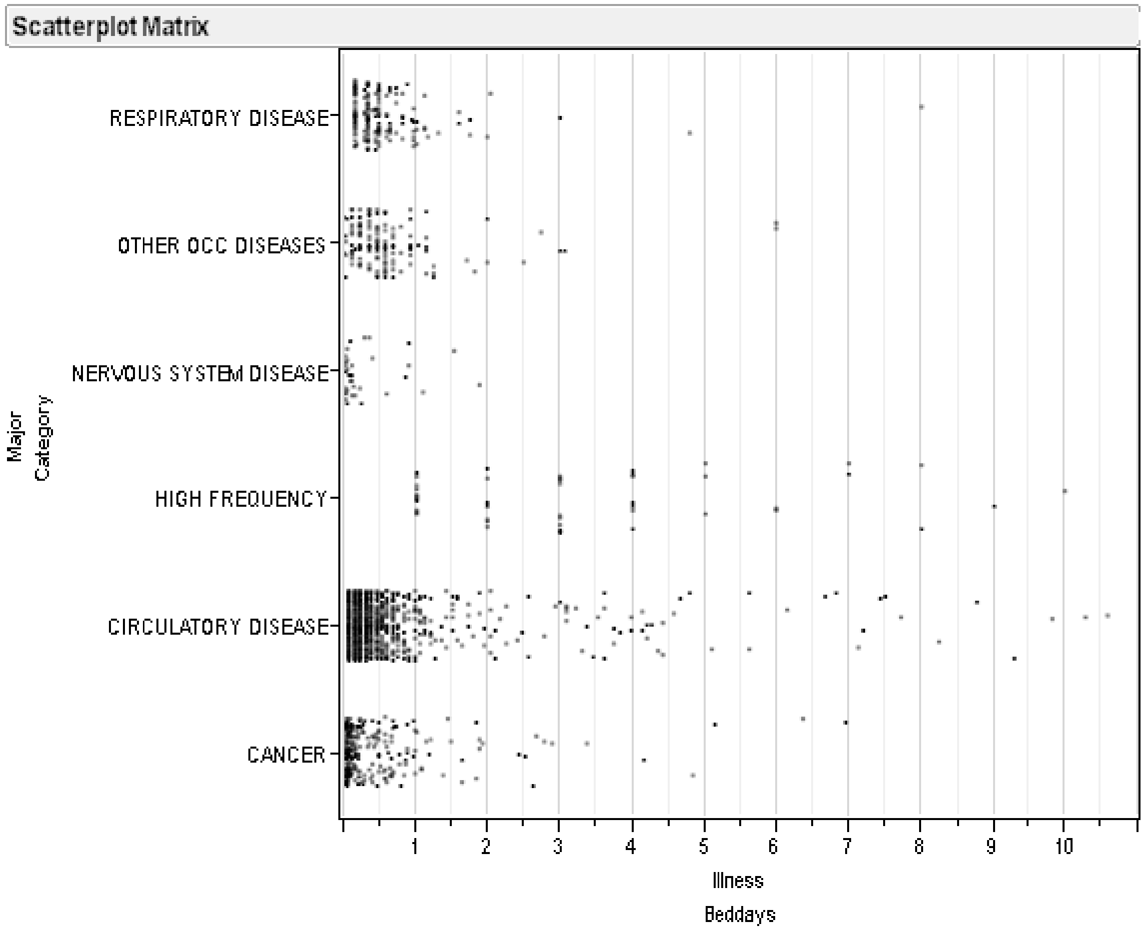
A5. Scatterplot of Military Care Observations: Disease Category and Bed Days



A6. Scatterplot of Purchased Care Observations: Disease Category/Illness Cost



A7. Scatterplot of Purchased Care Observations: Disease Category and Bed Days



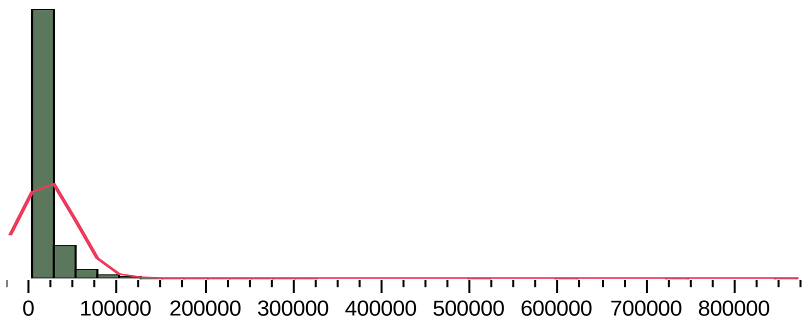
A8. Final DoD Total Cost Factor Regression Results, Military Care.

Variable	Estimate	Standard Error	t-statistic	Probability>t
Intercept	90.02	113.76	0.79	0.429
Occ Illness Bed Days	1781.23	40.89	43.57	0.000
Age (Continuous)	8.40	2.87	2.93	0.003
ACT LYM LEUK W/O RMSION	822.11	290.36	2.83	0.005
ACUTE NEPHRITIS NEC	5896.43	813.96	7.24	0.000
ACUTE RENAL FAILURE NOS	306.73	128.78	2.38	0.017
AMI ANTEROLATERAL, INIT	3199.68	575.33	5.56	0.000
AMI INFERIOR WALL, INIT	690.28	200.90	3.44	0.001
ANEURYSM, HEART (WALL)	3639.93	813.04	4.48	0.000
BACKACHE NOS	1616.57	232.15	6.96	0.000
BRONCHITIS NOS	-639.05	184.38	-3.47	0.001
CARPAL TUNNEL SYNDROME 3	2965.11	408.42	7.26	0.000
COR ATH ARTRY BYPAS GRFT	2598.04	1151.48	2.26	0.024
CRN ATH NONATLG BLG GRFT	2664.81	1149.48	2.32	0.021
CRNRY ATHRSCL NATVE VSSL	1197.85	97.95	12.23	0.000
DERMATITIS NEC	-4878.95	1165.21	-4.19	0.000
EMPHYSEMATOUS BLEB	2440.51	435.97	5.60	0.000
INTRACRANIAL HEMORR NOS	1144.95	436.78	2.62	0.009
MAL NEO ACCESS SINUS NEC	11807.23	1186.30	9.95	0.000
MAL NEO ETHMOIDAL SINUS	-5746.27	1171.94	-4.90	0.000
MAL NEO MAXILLARY SINUS	13304.27	1154.85	11.52	0.000
MAL NEO UPPER LOBE LUNG	2508.60	576.17	4.35	0.000
NONRUPT CEREBRAL ANEURYM	1066.29	333.48	3.20	0.001
PULMON TB NOS-MICRO DX	-1781.28	669.02	-2.66	0.008
SOLVENT DERMATITIS	-3278.66	1172.40	-2.80	0.005
SUBARACHNOID HEMORRHAGE 2	2073.46	335.04	6.19	0.000
SUBENDO INFARCT, INITIAL	654.57	135.90	4.82	0.000
SUBENDO INFARCT, UNSPEC	3354.83	813.44	4.12	0.000

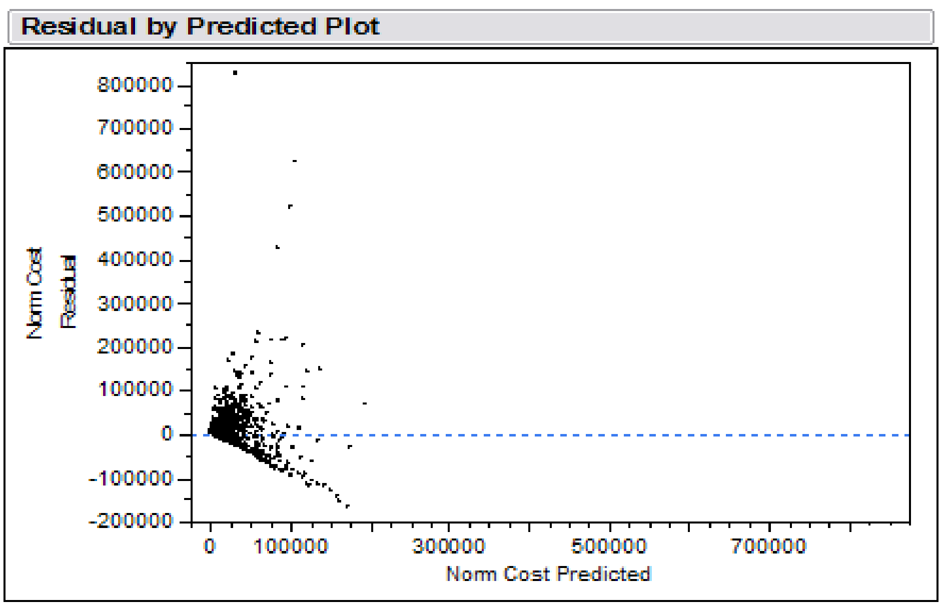
A9. Total Inpatient Care Diagnostics, Normalized Cost

Normality

Mean 16435.34
Std Dev 32756.98
Std Err Mean 519.03
Upper 95% Mean 17452.95
Lower 95% Mean 15417.74
N 3983
Goodness-of-Fit Test
KSL Test
D Prob>D
0.309055 < 0.0100
Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.



Heteroskedasticity



A10. Total Inpatient Care Diagnostics, Log Normalized Cost

Normality

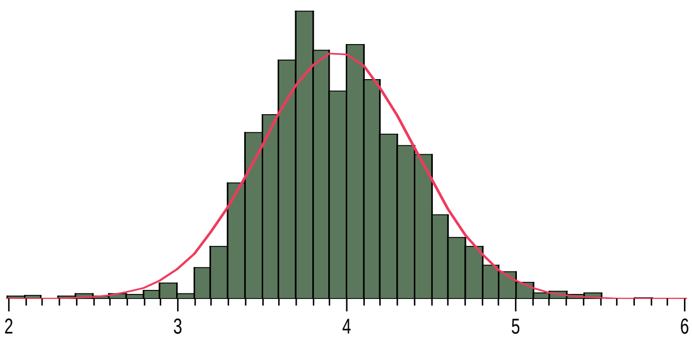
Mean	3.9461
Std Dev	0.45883
Std Err Mean	0.0072
Upper 95% Mean	3.9604108
Lower 95% Mean	3.9319033
N	3983

Goodness-of-Fit Test

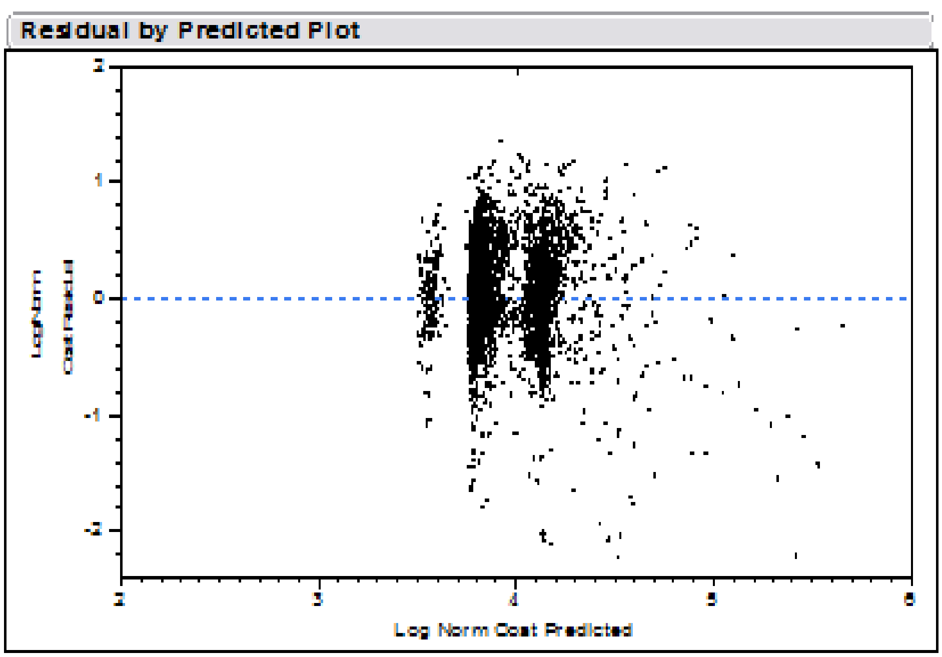
KSL Test

D		Prob>D
0.032059	<	0.0100

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.



Heteroskedasticity



A11. Total Inpatient Care Diagnostics, Normalized Occupational Illness Cost

Normality

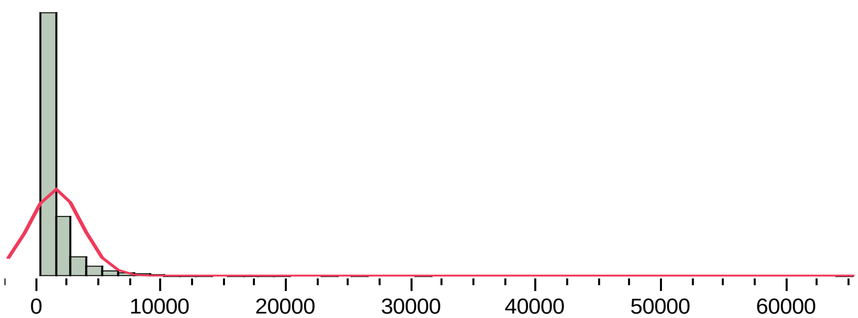
Mean	1267.08
Std Dev	2103.10
Std Err Mean	33.32
Upper 95% Mean	1332.41
Lower 95% Mean	1201.75
N	3983

Goodness-of-Fit Test

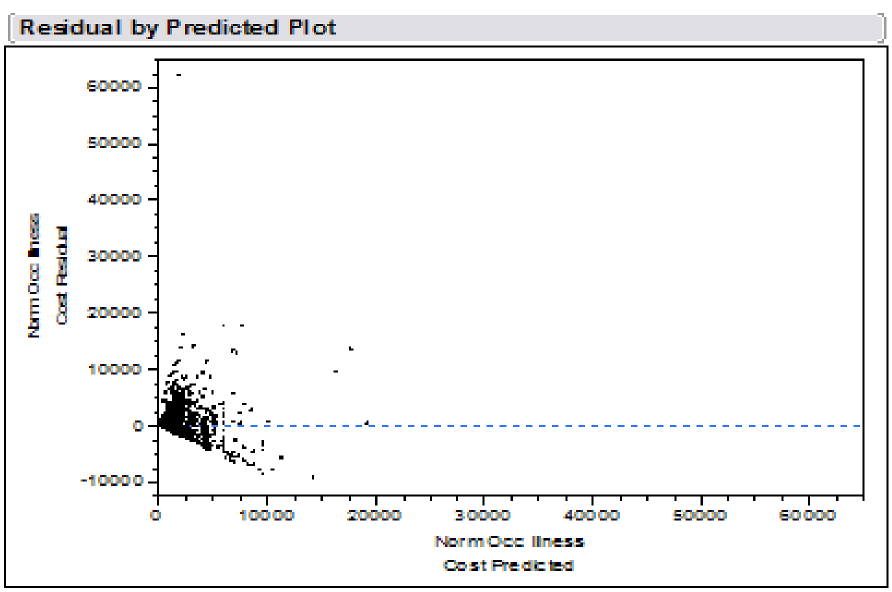
KSL Test

D		Prob>D
0.273964	<	0.0100

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.



Heteroskedasticity



A12. Military Inpatient Care Diagnostics, Normalized Cost

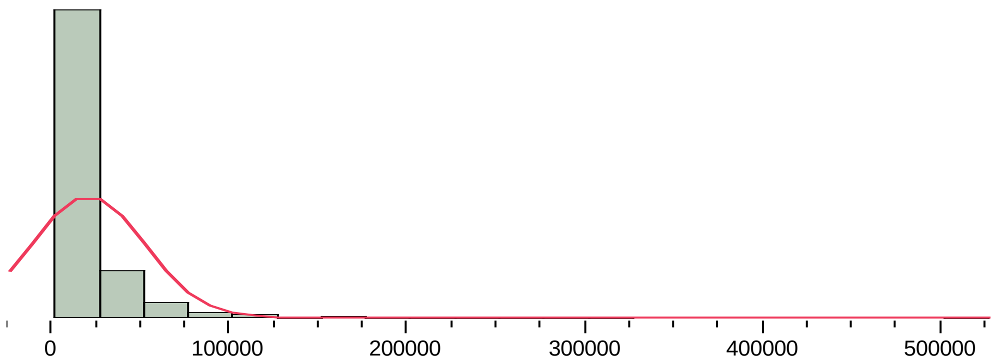
Normality

Mean	18795.48
Std Dev	31780.82
Std Err Mean	785.49
Upper 95% Mean	20336.15
Lower 95% Mean	17254.81
N	1637

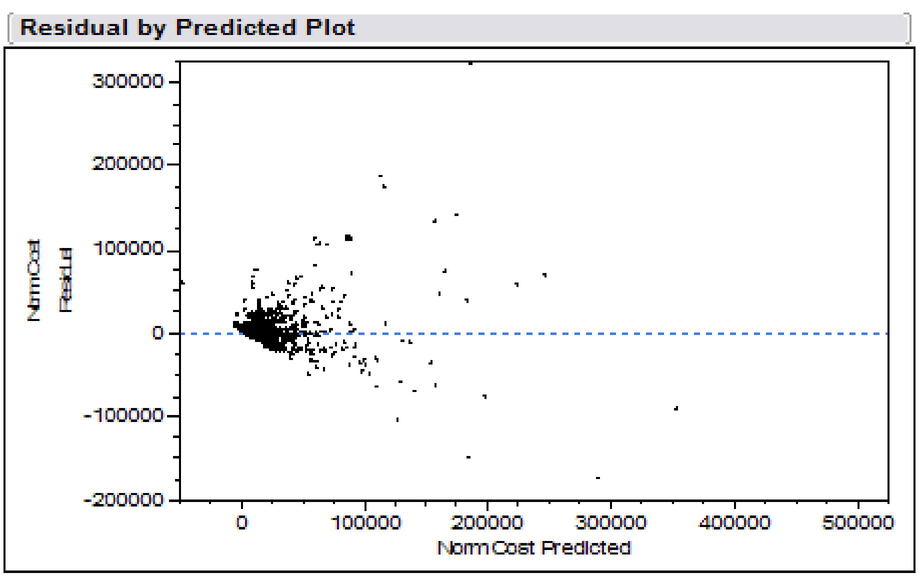
Goodness-of-Fit Test
 Shapiro-Wilk W Test

W	Prob<W
0.458134	0.0000

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.



Heteroskedasticity



A13. Military Inpatient Care Diagnostics, Log Normalized Cost

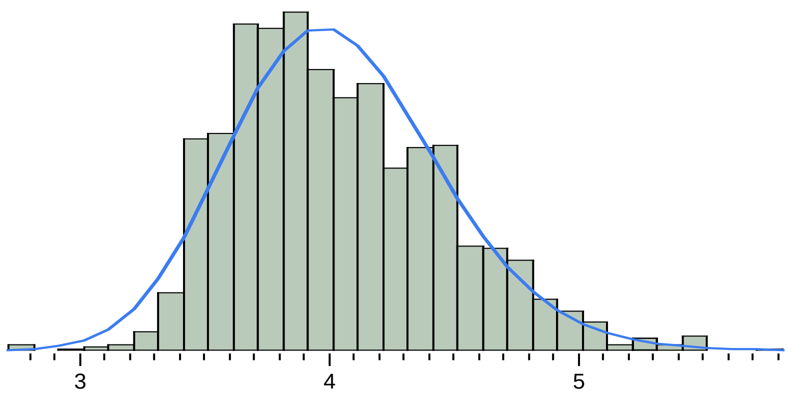
Normality

Mean	4.0225
Std Dev	0.4280
Std Err Mean	0.0105
Upper 95% Mean	4.0432
Lower 95% Mean	4.0017
N	1637

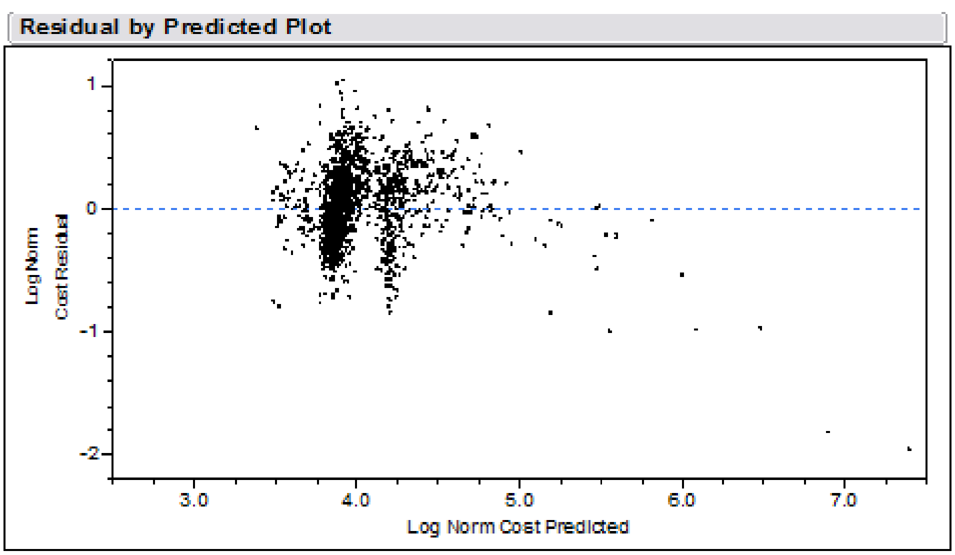
Goodness-of-Fit Test
Kolmogorov's D

D		Prob>D
0.050201	<	0.0100

Note: Ho = The data is from the LogNormal distribution. Small p-values reject Ho.



Heteroskedasticity



A14. Military Inpatient Care Diagnostics, Normalized Occupational Illness Cost

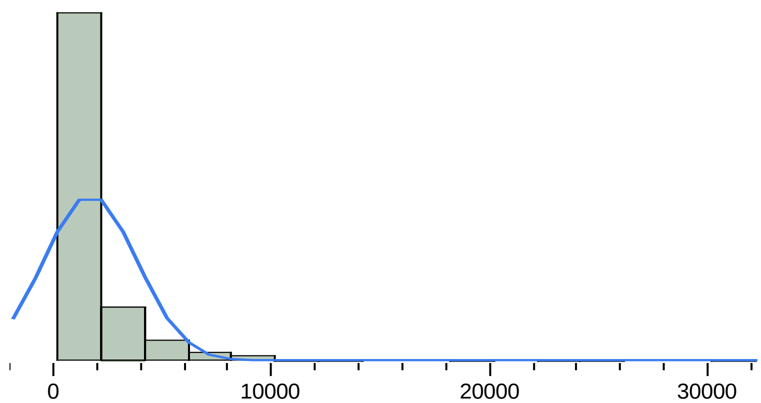
Normality

Mean	1502.42
Std Dev	2125.34
Std Err Mean	52.5298
Upper 95% Mean	1605.45
Lower 95% Mean	1399.39
N	1637

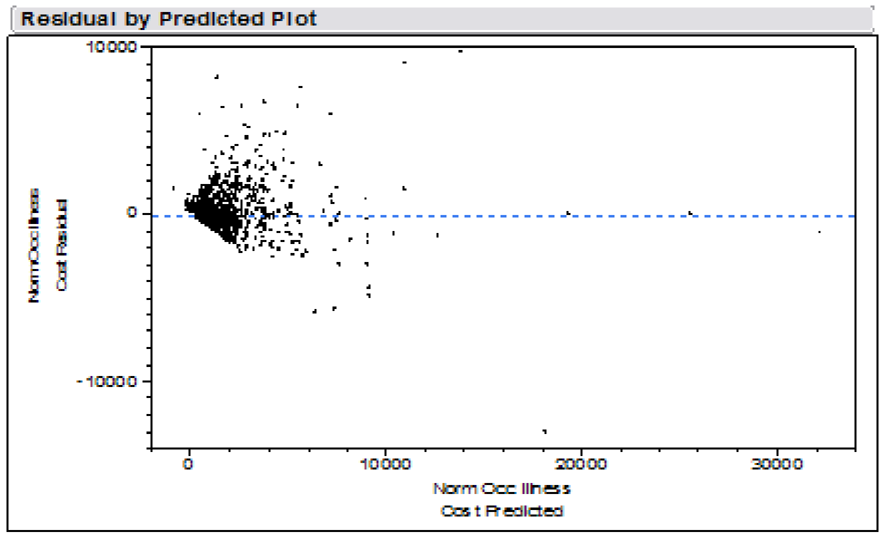
Goodness-of-Fit Test
Shapiro-Wilk W Test

W	Prob<W
0.557554	0.0000

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.



Heteroskedasticity



A15. Purchased Inpatient Care Diagnostics, Normalized Cost

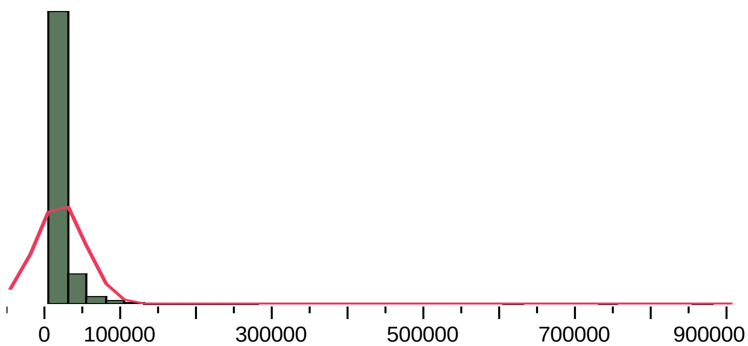
<u>Normality</u>

Mean		14788.48
Std Dev		33329.08
Std Err Mean		688.11
Upper 95% Mean		16137.85
Lower 95% Mean		13439.11
N		2346

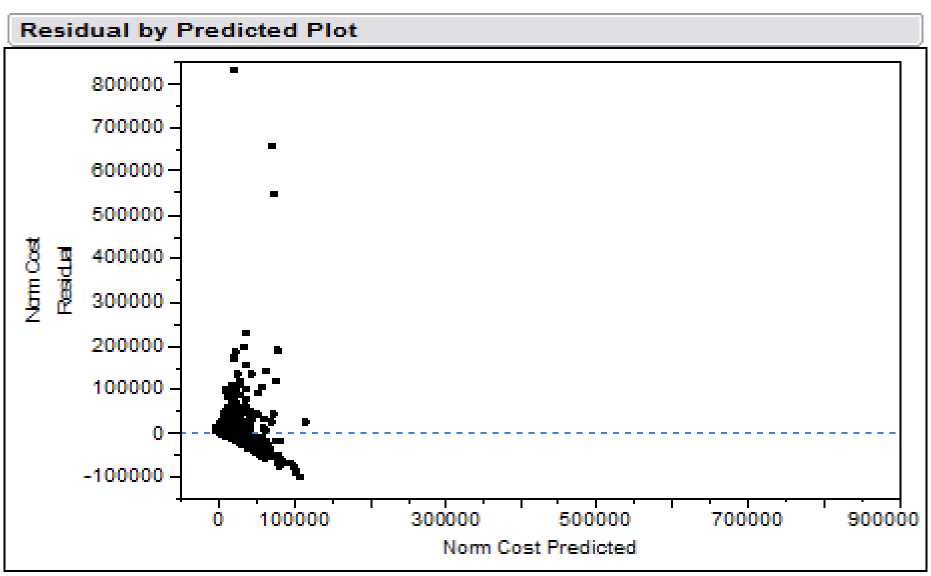
Goodness-of-Fit Test
KSL Test

D		Prob>D
0.329765	<	0.0100

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.



<u>Heteroskedasticity</u>



A16. Purchased Inpatient Care Diagnostics, Log Normalized Cost

Normality

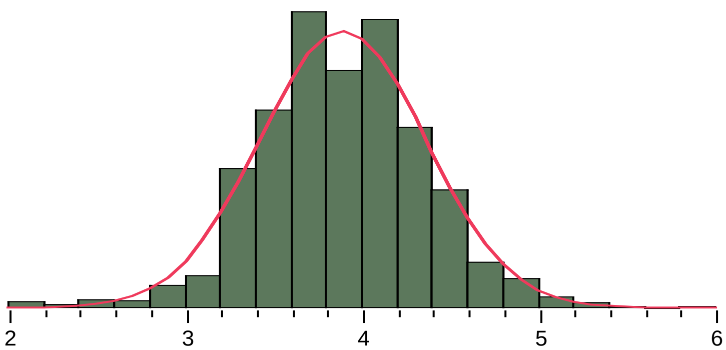
Mean	3.8928
Std Dev	0.4719
Std Err Mean	0.0097
Upper 95% Mean	3.911983
Lower 95% Mean	3.873768
N	2346

Goodness-of-Fit Test

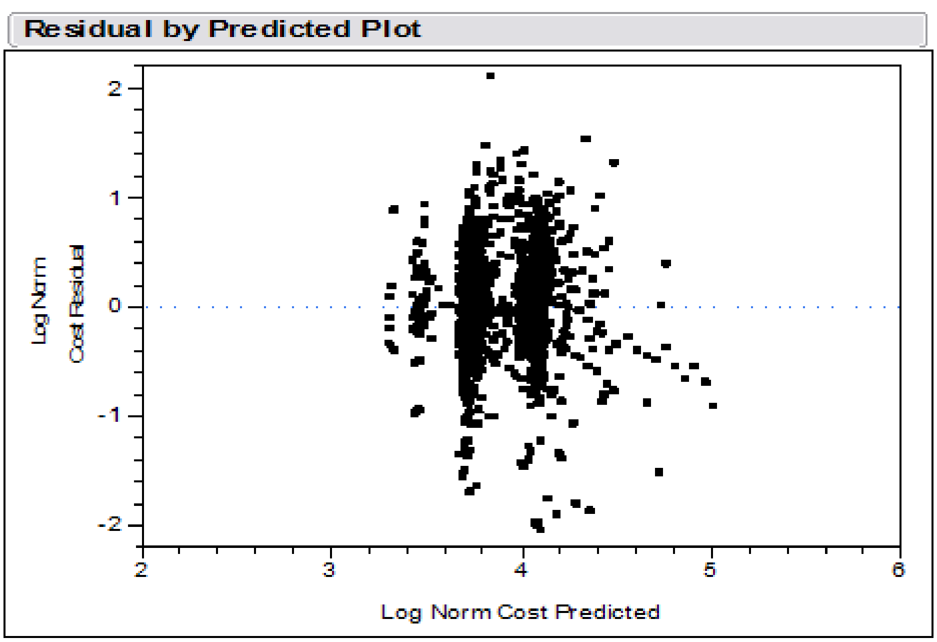
KSL Test

D		Prob>D
0.028913	<	0.0100

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.



Heteroskedasticity



A17. Purchased Inpatient Care Diagnostics, Normalized Occupational Illness Cost

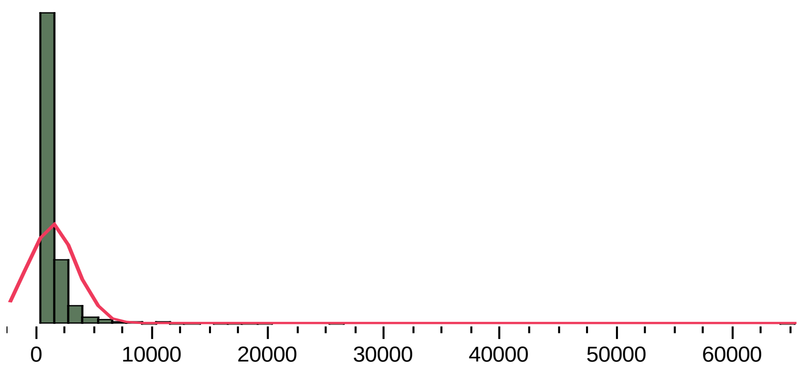
<u>Normality</u>

Mean	1102.86
Std Dev	2072.11
Std Err Mean	42.780
Upper 95% Mean	1186.75
Lower 95% Mean	1018.97
N	2346

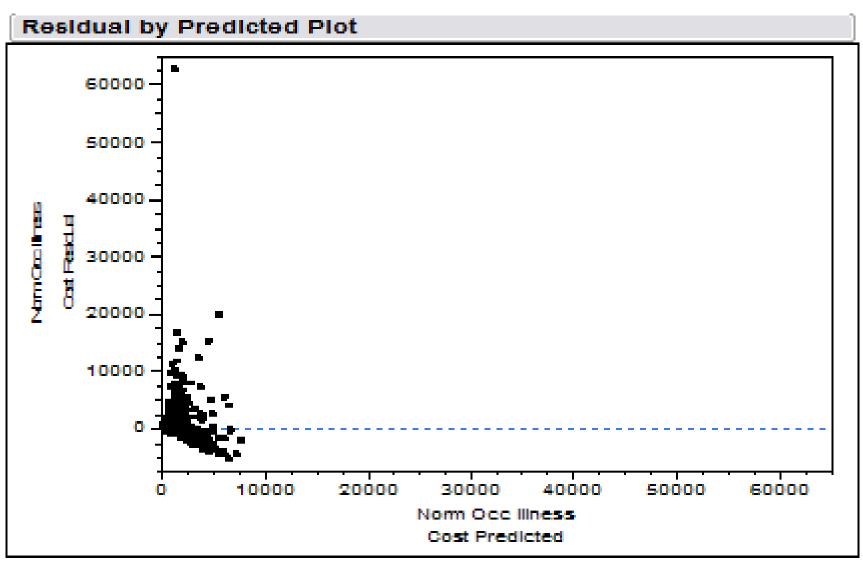
Goodness-of-Fit Test
 KSL Test

D		Prob>D
0.297847	<	0.0100

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.



<u>Heteroskedasticity</u>



A18. Parametric Estimates for Military Inpatient Care, Robust Standard Errors.

Variable	Estimate	Std Error	LR Chi^2	P>Chi^2
Intercept	90.021178	112.78004	0.6370015	0.4248
Age Continuous	8.398475	2.8431295	8.7026732	0.0032
ACT LYM LEUK W/O RMSION	822.11306	287.86959	8.135643	0.0043
ACUTE NEPHRITIS NEC	5896.4303	806.96926	52.538361	<.0001
ACUTE RENAL FAILURE NOS	306.72886	127.67603	5.7613743	0.0164
AMI ANTEROLATERAL, INIT	3199.6803	570.38698	31.16971	<.0001
AMI INFERIOR WALL, INIT	690.28367	199.17353	11.967502	0.0005
ANEURYSM, HEART (WALL)	3639.9258	806.05927	20.26563	<.0001
BACKACHE NOS	1616.568	230.1529	48.606181	<.0001
BRONCHITIS NOS	-639.0501	182.79691	12.176314	0.0005
CARPAL TUNNEL SYNDROME	2965.1116	404.90901	52.765385	<.0001
COR ATH ARTRY BYPAS GRFT	2598.0398	1141.5923	5.1711058	0.0230
CRN ATH NONATLG BLG GRFT	2664.8142	1139.6083	5.4588147	0.0195
CRNRY ATHRSCL NATVE VSSL	1197.8538	97.113428	145.4816	<.0001
DERMATITIS NEC	-4878.949	1155.1974	17.741269	<.0001
EMPHYSEMATOUS BLEB	2440.5126	432.22535	31.575227	<.0001
INTRACRANIAL HEMORR NOS	1144.9517	433.02879	6.9761387	0.0083
MAL NEO ACCESS SINUS NEC	11807.233	1176.1067	97.805741	<.0001
MAL NEO ETHMOIDAL SINUS	-5746.275	1161.872	24.279046	<.0001
MAL NEO MAXILLARY SINUS	13304.272	1144.9287	129.74799	<.0001
MAL NEO UPPER LOBE LUNG	2508.6021	571.22095	19.173855	<.0001
CEREBRAL ANEURYM1SM	2066.2866	330.61204	10.36894	0.0013
PULMON TB NOS-MICRO DX	-1781.275	663.2731	7.1965169	0.0073
SOLVENT DERMATITIS	-3278.658	1162.334	7.9373774	0.0048
SUBARACHNOID HEMRGE	2073.4588	332.16164	38.510001	<.0001
SUBENDO INFARCT, INITIAL	654.56833	134.73528	23.433393	<.0001
SUBENDO INFARCT, UNSPEC	3354.8306	806.45455	17.214558	<.0001
Occupational Illness Bed Days	1781.2291	40.533946	1275.4918	<.0001

A19. No Lost Time Factor, Normality Check Using Shapiro – Wilk Test.

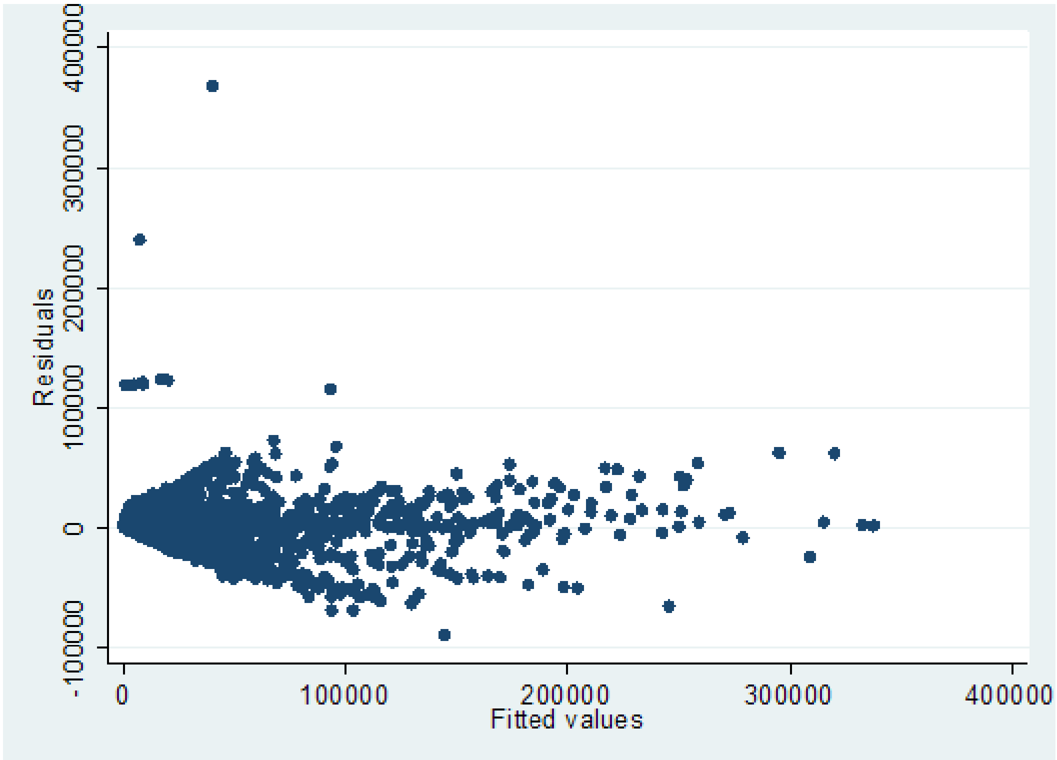
Shapiro-Wilk W test for normal data

Variable	Obs	W	V	z	Prob>z
Norm Occ Illness Cost	71872	0.13775	2.1e+04	27.743	0.00000

Ho: Data is from normal distribution.

Based on V coefficient, Ho is rejected.

A20. No Lost Time Factor Heteroskedasticity/Breusch-Pagan Test.



Breusch-Pagan LM statistic: 5087832 Chi-sq(1) P-value = 0

Heteroskedastic Robust Standard Error Results:

Number of obs = 71872
F(1, 71870) =10740.95
Prob > F = 0.0000
R-squared = 0.8870
Root MSE = 3778.8

Variable	Factor	Std. Err.	T-stat	P>|t	95% Conf Int	
Norm Occ Illness Cost	235.59	2.27	103.64	0.000	231.13	240.04
Constant	-27.18	13.50	-2.01	0.044	-53.64	-.72

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14. ABSTRACT
The primary purpose of this research was to improve the effectiveness of cost comparison analyses for the 75th Aerospace Medicine Group, Hill Air Force Base, Utah. Bioenvironmental engineers sought a more robust cost comparison tool, allowing engineers to quickly determine the viability of proposed occupational health-related expenditures. To justify the funding of potential projects, engineers must quantify the expected cost savings. Improved cost comparison analysis enables personnel to better justify worthy projects or filter out uneconomical solutions. A secondary purpose of this research was to validate Department of Defense (DoD) occupational illness cost factors. This research effort focused on cost factors for illnesses resulting in no lost work time and for illness resulting in hospitalization. The existing cost factors were developed in 1988, and no continuity or existing methodology is available to determine how the factors were developed. We modeled direct medical expenditures related to occupational illness for a specific set of illnesses for active duty Air Force personnel to validate the "no lost time" factor. Additionally, we attempted to validate and apportion the hospitalization factor into direct and indirect occupational illness costs. This new knowledge will allow leaders to plan for and mitigate potential occupational illness costs.

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